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Time Trend Analysis of the Plio-Pleistocene Sequence in the Central Part of Kinki District, Japan

By

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Abstract

A computer program has been designed to systematically process stratigraphical, time sequencial data for establishing the analytical methods of sedimentary environments. Using the program, a series of time trend analyses were performed on the fourteen sets of column data obtained from deep wells and outcrops of the Plio-Pleistocene sequence which is distributed in the Osaka Plain, the central part of Kinki district in Japan, and mainly consists of the Osaka Group.

As the result, the time trends extracted from the columns show a definite pattern in common with each other. The pattern indicates that the Plio-Pleistocene sedimentary sequence in this region can be divided into four parts in terms of the history of sedimentary environments. Each boundary appears to be consistent with the stratigraphical boundary of the Osaka Group generally accepted by many authors (Ikebe, N., 1970; and others).

It has been clarified that such a systematic time trend analysis as performed in the present study is very efficient for the understanding of the history of sedimentary environments. Furthermore, it has been also proved that the analysis can provide for processed data which are quite useful in the further comprehension of the history of sedimentary environments.

I. Introduction

Sedimentation generally takes place according to a certain trend called a trend of sedimentation. Such a trend, however, tends to be overlooked or misunderstood because of the existence of accidental factors in the records of sedimentation, i.e., in a sedimentary sequnece for example. Therefore, those accidental factors are required to be fully removed in order to well appreciate the trend of sedimentation. For this purpose, the time trend analysis is considered to be one of the most useful ways.

Vistelius (1967) has given the rock-ranging, which expresses the strength of erosion by means of a graded number, to the bed as one of parameters which quantitatively indicates the sedimentary environments. Then he extracted the trend of sedimentation by smoothing the oscillating curve formed by a sequence of the parameters, and succeeded to obtain the several trends of sedimentation concerning some sedimentary sequences of the Permian, the Pliocene and other ages. Thereby, he

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has been successful in the correlation of columns observed from such sedimentary sequences that scarcely bear either characteristic mineral associations or significant fossils. As for the correlation, however, he emphasized in his works the necessity of existence of a common trend among the columns to be correlated.

A series of time trend analyses have been made on the several sets of the column data derived from wells and outcrops relating mainly with the Osaka Group*. The purposes of the present investigation are as follows:

(1) Designation of a systematic procedure and a computer program for the time trend analysis of sedimentary processes.

(2) Confirmation of the presence of any trend in common with all the columns concerned with such a group as the Osaka Group, in which some sedimentary facies abruptly changed their thickness and/or compositions.

(3) Examination of the applicability of a trend of sedimentation, if any, to the correlation among sedimentary sequences.

(4) To investigate that what sorts of suggestions for the study of sedimentary processes are obtained as the result of time trend analysis.

* The Osaka Group, the Plio-Pleistocene strata, distributed in the central part of Kinki district, consists of unconsolidated gravels, sands and muds, and partly contains marine clay beds and volcanic ash layers (Fig. 1). The age of this group ranges from early Matsuyama reverse epoch to middle Brunhes normal epoch. The total thickness is 300–400 metres at the hillside, but generally much thicker under the alluvial plain. The lower part of the group consists mainly of sand and gravel beds; the middle to upper part is composed of the alternation of sand-gravel beds and 11 layers of marine clay bed, which are named Ma 0, Ma 1, Ma 2, and so on upward. Ma 3 contains "Azuki tuff" consisting of two pyroxene andesitic tuff. "Azuki tuff" is dated within Jaramillo event, and is one of the most useful key beds in the group as well as Ma 3 (Fig. 3).
The group yields a large amount of both animal and plant fossils. *Stegodon akashiensis* occurs in the horizons below Ma 0; *Elephas shigensis* from Ma 0 to Ma 5, and *Stegodon orientalis* above Ma 5. The temperate Tertiary flora is found in the horizons below Ma 3, while the cold flora becomes dominant from Ma 3. The assemblage of microfossils suggests that the alternation of sand-gravel beds and marine clay beds in the middle to upper part of the group indicates the fluctuation of sea level which occurred during the glacial and interglacial times.

II. Procedure

An intimate relationship is very likely to exist between particle sizes and their sedimentary environments, in other words, particle sizes can be considered to numerically indicate some aspect of their sedimentary environments. Therefore, it can be expected that the vertical transition of particle sizes well reflecs the history of sedimentary environments. The data obtained by the observations of them involves three kinds of factors, that is, a general trend (or functional trend), seasonal effects and random errors named $y(t)$, (t') and t respectively. The observation of a given series, z_t, is defined as

$$z_t = y(t) + \xi(t') + \varepsilon_t$$

where t' is a relative time in a season. Therefore, if $\xi(t')$ and ε could be sufficiently eliminated from the data of the observations, a certain general time trend of sedimentary environments would be extracted.

Although there are many techniques for this type of trend analysis, a moving smoothing method (5 and 21 terms) was applied for finding local and general trends and a Fourier analysis was supplemented for examining cyclic trends.

For the moving smoothings, two well known formulae as below were applied (VISTELIUS, 1967):

$$Z_{cal,i} = \frac{1}{35}\{17\cdot Z_i + 12\cdot(Z_{i-1}+Z_{i+1}) - 3\cdot(Z_{i-2}+Z_{i+2})\}$$

(for 5 terms one; $i=3, 4,\ldots, n-2$)

$$Z_{cal,i} = \frac{1}{350}\{60\cdot Z_i + 57\cdot(Z_{i-1}+Z_{i+1}) + 47\cdot(Z_{i-2}+Z_{i+2})$$

$$+33\cdot(Z_{i-3}+Z_{i+3}) + 18\cdot(Z_{i-4}+Z_{i+4})$$

$$+6\cdot(Z_{i-5}+Z_{i+5}) - 2\cdot(Z_{i-6}+Z_{i+6})$$

$$-5\cdot(Z_{i-7}+Z_{i+7}) - 5\cdot(Z_{i-8}+Z_{i+8})$$

$$-3\cdot(Z_{i-9}+Z_{i+9}) - 1\cdot(Z_{i-10}+Z_{i+10})\}$$

(for 21 terms one; $i=11, 12, \ldots, n-10$)

where n is the number of time points in a series of the observations, and they are equally spaced.

The Fourier analysis was performed as follows:

The Fourier coefficients of the Fourier sine and cosine series were obtained by the numerical integration. And the series was defined as

$$Z_{cal,k}(t) = a_0 + \sum_{i=1}^{k} a_i cos\,\frac{\pi i}{m}\,t + \sum_{i=1}^{k} b_i sin\,\frac{\pi i}{m}\,t;$$

$$m=(n-1)/2 \qquad \text{(when } n \text{ is an odd number)}$$

$$m=(n-2)/2 \qquad \text{(when } n \text{ is an even number)}$$

where k is the degree of the Fourier series, and

$$1 \leq k \leq m-1$$

Then, from the Fourier coefficients obtained by the formula above, the power-spectrums (SP^2) were calculated as follows (HARBOUGH, 1967):

$$SP_i^2 = a_i^2 + b_i^2$$

where i is the degree of the Fourier series. The power-spectrums indicate how each set of the coefficients influences the oscillation of the series. Hence, the major periods of the series, if any periodicity exists, could be observed in the power-spectrums. Furthermore, the nonbiased variance $\hat{s}^2$ for each series (its degree, k, is 1 to $m-1$) was calculated in order to observe the degree of fitness.

$$\hat{s}^2 = \frac{\Sigma(Z_t - Z_{cal}(t))^2}{n' - 2K - 1}$$

where n' reprensents either n, when n is an odd number, or $n-1$, when n an even one.

There exist some differences between the observational value Z_t and the calculated one $Z_{cal}(t)$. As a result, it may be seen that the values based on the observations are scattered around the curve of the calculated ones. In order to determine whether such a phenomenon described above satisfies randomness or has any trend, one of run tests was adopted. The test was performed to examine to what degree the seasonal effects and the random errors could be eliminated. The run test applied here was carried out according to the following principles:

In the first place, one can fix a sequence of both positive (+) and negative (−) elements depending on whether the individual observational value falls above or below the calculated value (or curve). Such a sequence may be illustrated as + + − + + − − − − + + for example. Hence, a run is defined as a sequence of one or more similar elements, preceded and followed by different elements (MILLER, 1962). In the example mentioned above, there are 12 elements, and 7 of them are positive (+) and the remained 5 negative (−), and there are 5 runs. Then if it is assumed that the sequence of the elements is ordered at random, one could estimate the expectation and the standard deviation of the runs from the numbers of both the positive (+) and the negative (−) elements. Therefore, it can be examined whether the number of the observed runs is exceptionally low or high as compared with the estimated expectation, and consequently the assumption could be evaluated.

In time trend analysis, it is often required to examine if a time series has any periodicity, and if any, the period should be inferred. In order to satisfy the requirement, one of the autocorrelation analyses was performed. In the analysis, a time series partly overlapped itself, and the correlation coefficient was computed in the overlapped part. The overlapped part was gradually moved, and a series of the correlation coefficients was obtained as a function $K(\tau)$, as follows (VISTERIUS, 1967):

$$K(\tau)=\frac{\sum_{i=1}^{m} x_i\cdot x_{i+\tau}-\sum_{i=1}^{m} x_i\cdot\sum_{i=1}^{m} x_{i+\tau}/m}{(\sum_{i=1}^{m} x_i^2-(\sum_{i=1}^{m} x_i)^2/m)(\sum_{i=1}^{m} x_{i+\tau}^2-(\sum_{i=1}^{m} x_{i+\tau})^2/m)};$$

$m=n-\tau$ (n is the number of the observation points)

where τ is the lag value for overlapping, and x_i is either the observational or the calculated value. The better the fittness of overlapped part is, the nearer the value of $K(\tau)$ is to $+1$. Therefore, it is possible to infer the period of the periodicity, if any.

Before starting a series of the analysis mentioned above, it is required to collect such data that the values are both quantitative and continuous, and the observed time points are equally spaced. Actually, however, lithological characters are usually described in a qualitative manner in the most of data from wells and outcrops. Therefore, in the present investigation, all the data were converted to quantitative ones which have been named "assumed mean size", as the following manner:

Firstly, the sediments were divided into four components, that is, into gravel, sand, silt and clay, and the numerical grades, 24, 12, 4 and 0.5, were given to them respectively. Then, the proportion of the components at every one metre was calculated from the lithological description of a given series. And the ratios multiplied by the grade were totalled. Finally, the average of the totals of every 10 metres in the column of the series provided the assumed mean size.

III. Results

In the present investigation were processed 14 sets of column data, 12 of which were obtained from wells and the rests from outcrops. The locality of the samples is shown in Fig. 1, and some comments on the data are given in Tab. 1. All the data were offered by Dr. S. ISHIDA of Kyoto University.

The data were processed by the four kinds of analyses described in Chapter II: the moving smoothing method, the Fourier analysis, the run test and the autocorrelation analysis. The results were output from a computer in certain printed forms, graphs or tables.

Several examples, the results on the data No. 2 SHIGINO, are displayed in Fig. 2 and Tab. 2. The results of the moving smoothings are graphically shown in Fig. 2a. Where L is the sequence number of the units, numbered from the top of the column. Each unit has the thickness of 10 metres. Hence the value 10×L represents the depth. G(L), Y5(L), Y21(L) in Fig. 2a are the assumed mean size and the calculated values of 5 and 21 terms moving smoothings respectively. In

Fig. 2b are shown the given power-spectrums and the nonbiased variance of each Fourier series. Where FA(N) and FB(N) are Fourier coefficients; cosine and sine respectively. The graph indicates that the values of the power-spectrums for N=2, 4, 10 and 14 are especially large (the one for N=1 should be excluded, because it means the simple average of observations). It suggests the presence of some periodical trends whose wave lengths are 470, 157, 52 and 36 metres (corresponding to N=2,

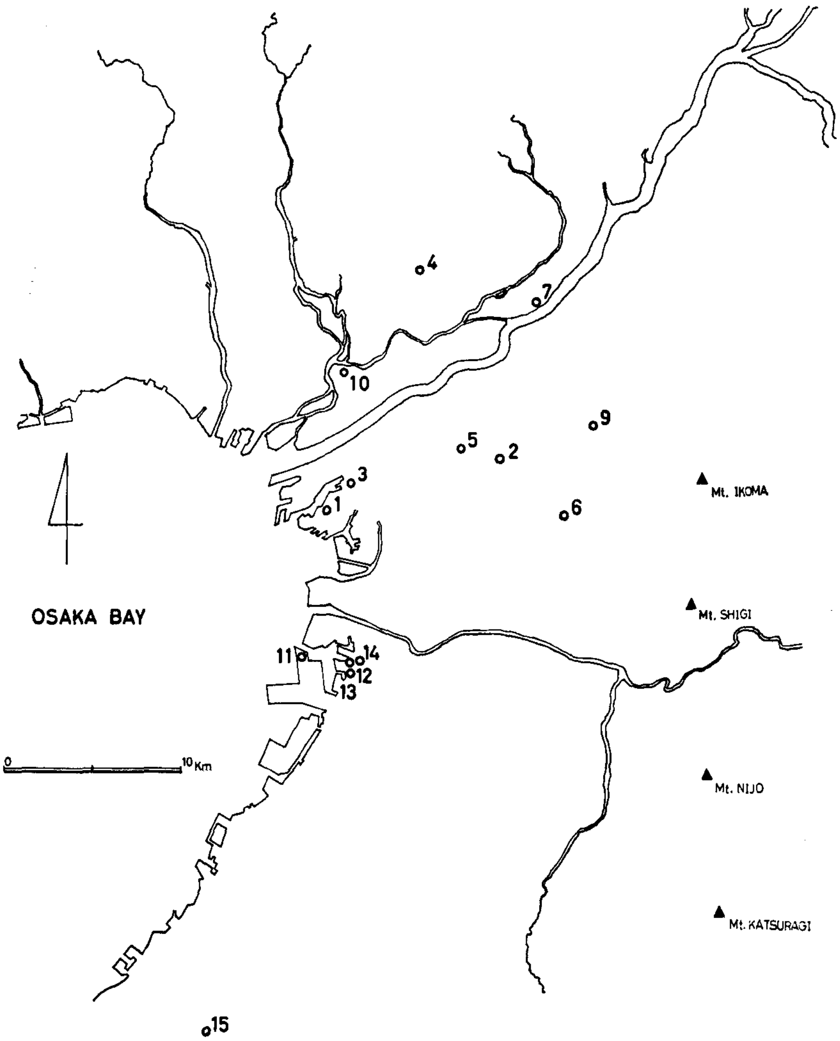


Fig. 1. Location of well and outcrop.

Tab. 1. Data (from well and outcrop).

NO. & NAME OF WELL/OUTCROP		TIP DEPTH OR TOTAL THICKNESS	REFERENCES
1.	OD–1	907 m	Publishing Committee for the Ground of Osaka (1966)
2.	SHIGINO	500 m	———— (1966); IKEBE *et al.* (1970)
3.	KASUGADE	430 m	———— (1966); ———— (1970)
4.	SENRIYAMA*	374 m	ITIHARA (1961); ITIHARA & TAKETSUJI (1967)
5.	OD–2	667 m	Publishing Committee for the Ground of Osaka (1966)
6.	FUSE	700 m	
7.	HOKUSETSU	360 m	Publishing Committee for the Ground of Osaka (1966); INAI & ISHIDA (1966)
9.	DAITOSHI (OD–6)	500 m	IKEBE *et al.* (1970)
10.	AMAGASAKI (OD–5)	700 m	———— (1970)
11.	SAKAI–6–3B	300 m	MATSUSHITA (1967)
12.	SAKAI–4–1	250 m	———— (1967)
13.	SAKAI–4–2	250 m	———— (1967)
14.	SAKAI–4–3	250 m	———— (1967)
15.	KOKIGAWA*	210 m	HARATA *et al.* (1963)

* outcrop

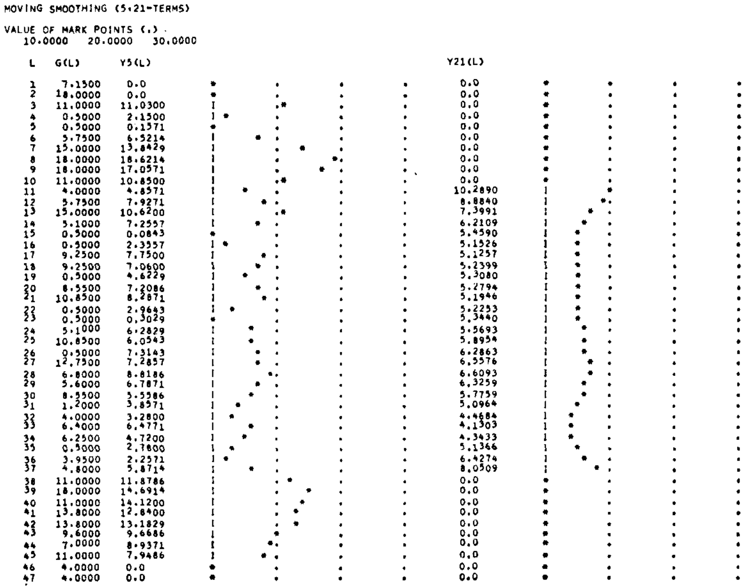


Fig. 2a. Output example of moving smoothing (data: SHIGINO).

FOURIER ANALYSIS
FOURIER COEFFICIENTS, POWER SPECTRUM AND VARIANCE

N	COS FA(N)	SIN FB(N)	POWER SPECTRUM SIG2(N)		VARIANCE VAR(N)	
1	7.6092	0.0	0.57901E 02	*********************	0.27154E 02	*******
2	2.5290	0.5075	0.66535E 01	******************	0.28351E 02	*******
3	-0.1446	-0.3257	0.12699E 00	*	0.25119E 02	******
4	-1.6156	-2.2781	0.78002E 01	*********************	0.24722E 02	******
5	-1.1748	-1.2326	0.28995E 01	********	0.24320E 02	******
6	1.4811	0.8175	0.28620E 01	********	0.24044E 02	******
7	0.4222	1.4850	0.23834E 01	*******	0.23016E 02	*****
8	1.2462	1.5379	0.39182E 01	***********	0.22294E 02	*****
9	-1.2859	0.8156	0.23188E 01	*******	0.18334E 02	****
10	-2.3121	-0.6182	0.57281E 01	****************	0.17891E 02	****
11	-0.9321	-0.9887	0.18463E 01	******	0.18080E 02	****
12	1.4277	-0.0601	0.20419E 01	******	0.16716E 02	***
13	-1.4637	-0.2388	0.21993E 01	*******	0.11993E 02	**
14	0.5684	-2.5326	0.67370E 01	******************	0.13509E 02	**
15	0.3284	-0.1288	0.12442E 00	*	0.11004E 02	*
16	0.5290	-2.0120	0.43278E 01	************	0.98354E 01	*
17	-0.9564	-0.3221	0.10185E 01	****	0.11901E 02	**
18	0.3158	-0.4089	0.26696E 00	**	0.13959E 02	**
19	0.7864	-0.8609	0.13596E 01	****	0.15861E 02	***
20	0.5279	0.7576	0.85275E 00	***	0.15882E 02	***
21	1.0475	-1.4449	0.31852E 01	*********	0.24201E 02	******
22	0.0396	-0.0748	0.71611E-02	*	0.53372E 02	****************
23	0.8013	0.2096	0.68596E 00	***	0.69384E 02	*********************

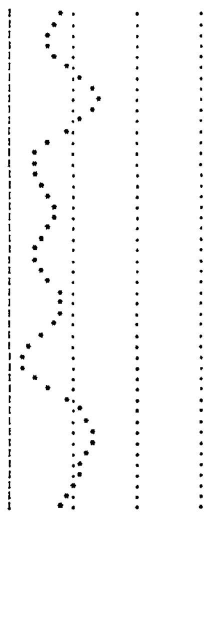
Fig. 2b. Output example of power spectrum and variance (data: SHIGINO).

FOURIER ANALYSIS - LOGICAL VALUES

VALUE OF MARK POINTS (.)
10.0000 20.0000 30.0000

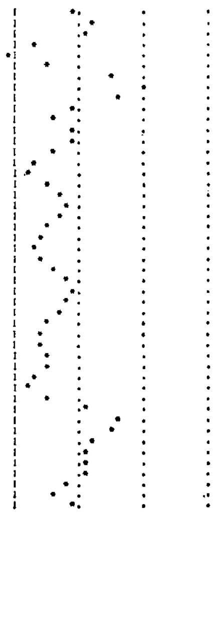
DEGREE 5

L	Z
1	7.5878
2	6.5877
3	6.0016
4	6.1532
5	7.2033
6	9.0166
7	11.1396
8	12.9198
9	13.7289
10	13.2056
11	11.4138
12	8.8428
13	6.2400
14	4.3370
15	3.5790
16	3.9672
17	5.0801
18	6.2654
19	6.9203
20	6.7427
21	5.8473
22	4.6994
23	3.8953
24	3.8880
25	4.7754
26	6.2444
27	7.6949
28	8.4915
29	8.2352
30	6.9403
31	5.0430
32	3.2384
33	2.2165
34	2.4051
35	3.8233
36	6.0979
37	8.6252
38	10.8024
39	12.2288
40	12.8001
41	12.6692
42	12.1124
43	11.3742
44	10.5703
45	9.6896
46	8.6843
47	7.5878



DEGREF 10

L	Z
1	8.5545
2	12.3446
3	10.6309
4	3.4787
5	-0.6929
6	4.6640
7	15.2059
8	20.4155
9	16.1977
10	8.9272
11	6.4175
12	8.5722
13	9.4682
14	6.3020
15	2.5228
16	2.2678
17	5.0563
18	7.4262
19	7.6164
20	6.5534
21	5.3438
22	4.0944
23	3.1654
24	3.6181
25	5.6618
26	7.8504
27	8.6252
28	7.9067
29	6.5765
30	5.2424
31	4.2861
32	4.2425
33	4.9453
34	4.9633
35	3.4803
36	2.4894
37	5.0920
38	10.9905
39	15.6500
40	15.4744
41	12.3192
42	10.6649
43	11.2638
44	10.7012
45	7.6255
46	5.8226
47	8.5545



FOURIER ANALYSIS - LOGICAL VALUES

VALUE OF MARK POINTS (.)
10.0000 20.0000 30.0000

DEGREE 15

L	Z
1	3.5973
2	14.0574
3	13.8776
4	-0.1994
5	-1.0063
6	8.2819
7	13.1015
8	18.2333
9	19.1497
10	9.8162
11	3.8039
12	7.7910
13	11.8894
14	7.8649
15	-0.8501
16	0.3303
17	10.2361
18	8.2650
19	1.1484
20	8.0759
21	11.3106
22	0.3796
23	-0.4949
24	7.8359
25	6.5672
26	5.1707
27	9.2370
28	8.1347
29	6.3648
30	6.6842
31	3.0139
32	2.8005
33	7.1915
34	5.3388
35	1.7460
36	2.7394
37	5.3057
38	11.6106
39	16.4532
40	12.8627
41	12.2250
42	14.8289
43	9.1054
44	6.8974
45	12.0394
46	7.2124
47	3.5973

DEGREE 20

L	Z
1	0.6241
2	17.4117
3	11.5337
4	0.0391
5	0.8711
6	5.4838
7	15.1486
8	17.9786
9	17.8879
10	11.2482
11	3.6171
12	6.2626
13	14.3662
14	5.8432
15	-0.3381
16	1.4165
17	8.2732
18	10.2684
19	-0.5412
20	9.5955
21	9.8174
22	1.5038
23	-0.4611
24	6.0064
25	10.0082
26	1.2692
27	12.0594
28	7.4075
29	5.0787
30	8.9831
31	0.8562
32	4.2538
33	6.2362
34	6.3241
35	0.5149
36	3.8474
37	4.9884
38	10.7287
39	18.3501
40	10.5767
41	14.2892
42	13.2541
43	10.1914
44	6.3764
45	11.6408
46	8.9336
47	0.6241

FOURIER ANALYSIS - LOGICAL VALUES

VALUE OF MARK POINTS (.)
10.0000 20.0000 30.0000
BEST FIT VALUES

DEGREE 16

L	Z
1	3.8858
2	14.6812
3	12.8698
4	0.3393
5	-0.6197
6	7.2973
7	13.8505
8	18.3541
9	18.2615
10	10.7198
11	3.6498
12	7.0650
13	12.8808
14	7.4474
15	-1.3600
16	1.3359
17	9.5862
18	8.0090
19	2.0936
20	7.2418
21	11.3274
22	1.1943
23	-1.4513
24	8.1244
25	7.1910
26	4.1629
27	9.7757
28	8.5213
29	5.3802
30	7.4331
31	3.1347
32	1.9123
33	8.0952
34	5.1847
35	1.0200
36	3.7308
37	4.8883
38	11.1007
39	17.4588
40	12.2129
41	11.9690
42	15.7741
43	8.2713
44	6.9143
45	12.8541
46	6.2559
47	3.8858

Fig. 2c. Output example of calculated value of Fourier analysis (data: SHIGINO).

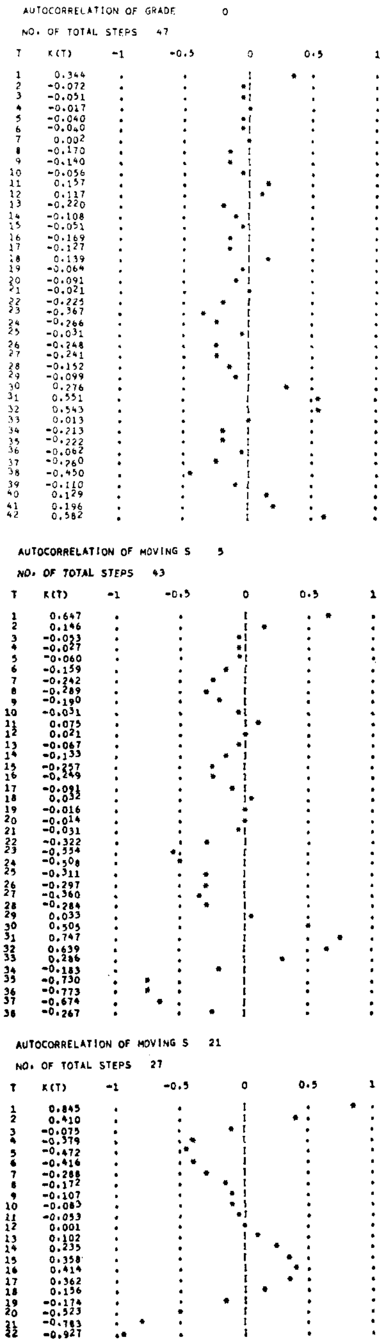


Fig. 2d. Output example of autocorrelation analysis (data: SHIGINO).

Tab. 2. Output example of run test (data: SHIGINO).

RUU TEST

		OBSERVED RUN	MEAN	VAR	LOGICAL LOWER	UPPER	PLUS	MINUS
MOVS	5	34	22.4884	10.4824	16.1427	28.8341	21	22
MOVS	21	15	14.0370	6.0357	9.2219	18.8522	11	16
FOUR	5	25	24.4894	11.4839	17.8474	31.1313	23	24
FOUR	10	29	24.4894	11.4839	17.8474	31.1313	23	24
FOUR	15	37	24.4043	11.3990	17.7869	31.0216	25	22
FOUR	20	43	24.4894	11.4839	17.8474	31.1313	24	23

4, 10, 14). It is also estimated from the graph that the 15 degree Fourier series (N=16) is the best fit series for the observations. The calculated values of Fourier series are illustrated in Fig. 2c, where N-1 is the actual degree of series. The larger the degree of series is, the more complicated the graph becomes. The results of the run test are systematically printed out as shown in Tab. 2. MOVS and FOUR represent the moving smoothing and the Fourier analysis respectively. The table shows the position of the number of observed runs with regard to the lower and upper 95% confidential limits. When the number of observed runs is not in the given confidential interval, it is necessary to reject the hypothesis that the observations are randomly scattered around the calculated curve. Therefore, if the number is smaller than the value of the lower limit, one could expect the existence of a more cyclic trend (periodicity with a shorter period, for example). Whereas, if the number is larger than that of the upper limit, he could predict the existence of a more linear trend. In this case are not excluded the trends which are indicated by the curve obtained by 21 terms moving smoothing and the curves of Fourier series for N=5 and 10, but are rejected the trends indicated by the one of 5 terms moving smoothing and the ones of Fourier series for N equal to or larger than 15.

The results of the autocorrelation analysis are shown in Fig. 2d. The analysis was performed on the series of assumed mean sizes (see Chapter II) and the ones resulted from 5 and 21 terms moving smoothings.

All the results of the analyses are rearranged in Tabs. 3 and 4, and Figs. 3 and 4.

The results of the Fourier analysis are shown in Tab. 3. In the right side column, the set numbers of Fourier coefficients, which show especially large power-spectrums, are given with their corresponding wave length in parentheses. Except the data of the four locations (OD-1, KASUGADE, OD-2, and KOKIGAWA), they indicate that the sets corresponding to 30 to 40 metres wave-lengths possess some peculiarly large power-spectrums. It suggests the presence of a certain periodicity with such a wave-length as mentioned to be common. This wave-length seems to correspond approximately to the vertical distance between two succeeding marine clay beds.

The result of the run test is given in Tab. 4. Those observed runs (see Chapter II), which stay within the 95% logical confidential interval, were framed. The values in parentheses show the corresponding wave-length of 50 to 80 metres, and are about double of the wave-length, which is shown by the shorter periodicity suggested before by resulting power-spectrums of the Fourier analysis. Further, it can be concluded that the shorter one has unreasonably too high frequency to be accepted as a general trend, because the hypothesis that the observed values, the assumed mean sizes in this case, are randomly scattered around the computed curve of the Fourier series, is rejected with respect to the shorter one of the periodicity. As a result, it seems suitable to adopt the periodicity, of which wave-length is 50 to 80 metres, as the one indicating the shortest significant wave-length. Namely, there is scarcely significance to accept any periodicity with a shorter wave-length than the one concluded above as a general trend, because such a periodicity could not reject a null hypothesis that the periodicity is due to random errors on a significant level. The wave-length of 50 to 80 metres corresponds to approximately the vertical distance between two marine clay beds inserting another marine clay bed between them, the distance between Ma 6 and Ma 4 for example.

As has been mentioned already, it is required to statistically examine the relation between the observations and the calculated values (the expected trend). Therefore, the periodicity and its wave-length must not be estimated only through the result of the Fourier analysis. Most of the best fit Fourier series shown in Tab. 3 are supposed to possess numerous runs exceeding the upper 95% confidential limit. Hence, it ought to be realized that all the best fit do not always show the general trend of the time series, and, moreover, such a series is unsuitable for either exclusion of the sea-

Tab. 3. Result of Fourier analysis.

OUTCROP /WELL NO.	OUTCROP /WELL NAME	BEST-FIT DEGREE	BASIC WAVE LENGTH (M)	NO. OF COEFFICIENT & CORRESPONDING WAVE LENGTH (M) WHICH HAS ESPECIALLY LARGE POWER-SPECTRUM
1	OD-1	36	870	2(870), 3(435), 11(87)
2	SHIGINO	16	470	2(470), 4(157), 10(52), 14(36)
3	KASUGADE	17	380	2(380), 4(127), 7(63)
4	SENRIYAMA*	3	340	10(38), 15(24)
5	OD-2	29	620	2(620)
6	FUSE	22	690	21(35)
7	HOKUSETSU	9	330	7(55), 10(37)
9	DAITOSHI	1	480	18(28)
10	AMAGASAKI	22	680	23(31)
11	SAKAI-6-3B	9	290	4(97), 8(36)
12	SAKAI-4-1	9	230	4(77), 8(33), 9(29)
13	SAKAI-4-2	2	230	6(38), 9(29)
14	SAKAI-4-3	2	230	2(230), 6(38)
15	KOKIGAWA*	4	200	3(100)

* outcrop data

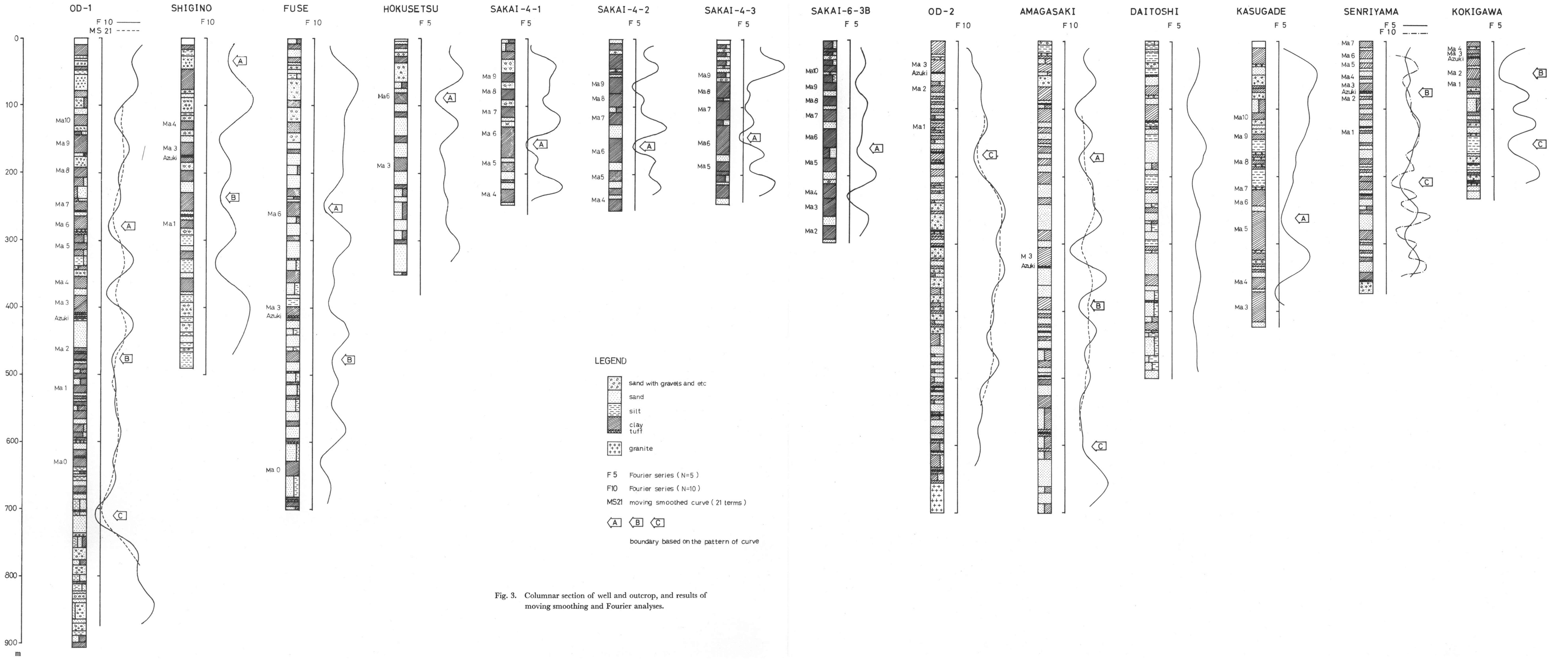


Fig. 3. Columnar section of well and outcrop, and results of moving smoothing and Fourier analyses.

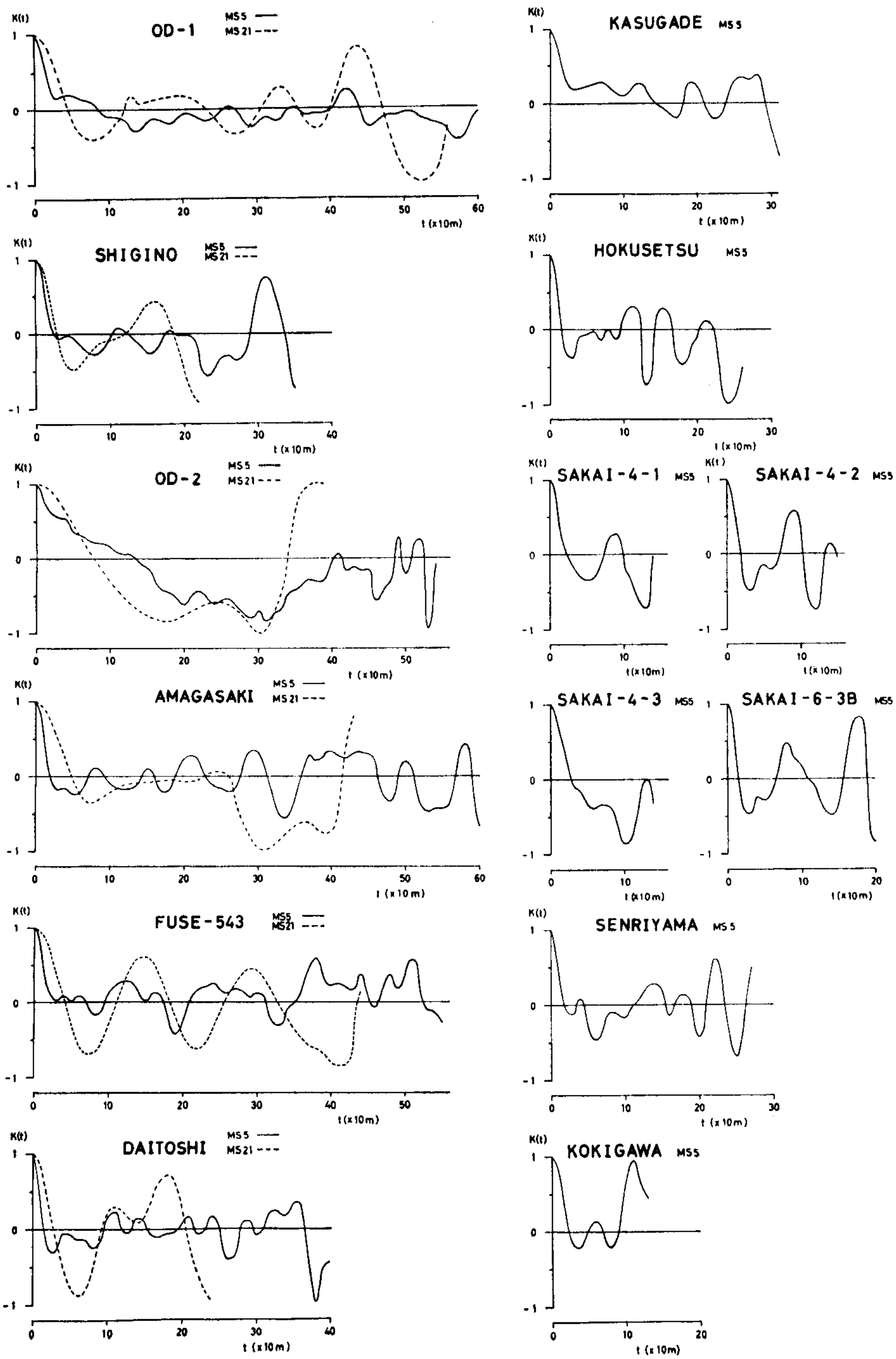


Fig. 4. Result of autocorrelation analysis.

Tab. 4. Results of run test. Those within the logical limits are framed.

NO. & NAME OF WELL/OUTCROP	KIND OF** APPROX.		OBSERVED RUNS	LOGICAL MEAN	95% LIMIT LOWER	95% LIMIT UPPER
1.	MOVS 5		58	42.9	34.0	51.8
OD-1	21		30	34.3	26.4	42.1
	FOUR 5		37	44.0	35.0	53.0
	10		43	44.0	35.0	53.0
	15	(62)	45	43.2	34.4	52.0
	20		55	44.4	35.4	53.5
	25		63	44.4	35.3	53.4
2.	MOVS 5		34	22.5	16.1	28.8
SHIGINO	21		15	14.0	9.2	18.9
	FOUR 5		25	24.5	17.8	31.1
	10	(52)	29	24.5	17.8	31.1
	15		37	24.5	17.8	31.1
	20		43	24.5	17.8	31.1
3.	MOVS 5		26	19.0	13.2	24.8
KASUGADE	21		9	10.9	6.7	15.1
	FOUR 5	(95)	21	20.4	14.4	26.4
	10		29	20.4	14.4	26.4
	15		33	20.5	14.5	26.5
4.	MOVS 5		25	16.9	11.5	22.4
SENRIYAMA*	21		12	8.9	5.2	12.6
	FOUR 5	(85)	23	17.8	12.3	23.3
	10		27	18.4	12.7	24.0
	15		33	18.5	12.8	24.2
5.	MOVS 5		51	30.9	23.4	38.4
OD-2	21		29	23.0	16.6	29.4
	FOUR 5	(155)	43	32.3	24.6	40.0
	10		47	32.3	24.6	40.0
	15		47	32.3	24.6	40.0
	20		49	32.3	24.6	40.0
	25		55	32.5	24.8	40.2
	30		61	32.5	24.8	40.2
6.	MOVS 5		46	33.4	25.6	41.3
FUSE	21		25	25.2	18.5	32.0
	FOUR 5		36	35.3	27.3	43.3
	10		40	34.6	26.8	42.5
	15		44	35.1	27.1	43.1
	20		48	35.4	27.4	43.6
7.	MOVS 5		19	15.9	10.7	21.2
HOKUSETSU	21		8	8.0	4.5	11.5
	FOUR 5	(83)	20	17.1	11.7	22.5
	10		25	17.5	11.9	23.0

	15		31	17.5	11.9	32.0
9.	MOVS 5		31	23.0	16.6	29.3
DAITOSHI	21		14	14.1	9.4	18.8
	FOUR 5		29	25.2	18.5	32.0
	10	(53)	31	25.5	18.7	32.3
	15		35	25.5	18.7	32.3
	20		43	25.4	18.6	32.2
10.	MOVS 5		50	33.5	25.7	41.3
AMAGASAKI	21		28	25.4	18.6	32.3
	FOUR 5		37	35.4	27.4	43.5
	10	(10)	39	35.5	27.4	43.5
	15		45	35.4	27.4	43.5
	20		49	35.4	27.4	43.5
	25		57	35.4	27.4	43.5
11.	MOVS 5		19	13.0	8.4	17.6
SAKAI-6-3B	FOUR 5	(73)	17	15.5	10.3	20.6
	10		23	15.3	10.2	20.5
12.	MOVS 5		15	10.5	6.3	14.6
SAKAI-4-1	FOUR 5		18	12.5	7.9	17.1
	10		21	12.5	7.9	17.7
13.	MOVS 5		15	10.9	6.7	15.1
SAKAI-4-2	FOUR 5	(58)	17	12.5	7.9	17.1
	10		21	12.5	7.9	17.1
14.	MOVS 5		13	9.8	6.0	13.7
SAKAI-4-3	FOUR 5	(58)	15	12.5	7.9	17.1
	10		21	12.5	7.9	17.1
15.	MOVS 5		12	9.6	5.7	13.4
KOKIGAWA*	FOUR 5	(50)	13	11.3	7.0	15.6
	10		21	11.5	7.1	15.8

* outcrop data

** Corresponding wave length is given in parentheses.

sonal effects or extraction of the general trend.

Therefore, it seems reasonable to adopt the Fourier series for N=5 and 10. In the present study, those for N=5 (F5) and N=10 (F10) were applied for the deep wells, and for the relatively shallow wells and the outcrops, respectively. As a result, all the shortest wave-lengths of the Fourier series were nearly same with each other, that is, 60 to 90 metres. Furthermore, the several results of 21 terms moving smoothings were adopted as such curves that indicated the more general trends. Those curves and the column sections are illustrated in Fig. 3. It can be suggested that the strata including the Osaka Group and the underlying beds are divided into the four major parts as follows:

(1) The part above Ma 6*; with a rather smooth trend.
(2) From Ma 6 to Ma 2; the fairly high oscillating part.
(3) From Ma 2 to the point of the peculiarly low value of the wave appearing just below Ma 0; with a relatively smooth trend.
(4) The one below the point mentioned above; with a relatively smooth trend.

It should be noted that the boundaries of the four parts, that is, the minimum points around Ma 6, Ma 2 and just below Ma 0, are identified in most of the data. Especially the last one is clearly identified (Fig. 3). There are, however, several peculiar differences concerned with the lowest part (4), namely, the part below Ma 0, between OD–2 and SENRIYAMA.

The curve of OD–2 suddenly rises after sinking at just below Ma 0 as in the case of OD–1, while the curve of SENRIYAMA does not show such a sign so clearly.

The results of the autocorrelation analysis are illustrated in Fig. 4. The curves show the sequence of the autocorrelation coefficients concerned with the results of 5 and/or 21 terms moving smoothing. Coefficient $K(t)$ and lag t are represented by the vertical and horizontal axes respectively.

Those graphs show that all the sequences of the coefficients, except the one of OD–2, rise up to the positive side around $t=80$ and/or 150 metres. The fact suggests that the series of assumed mean size are equipped with the periodicity of such periods. The longer period of them nearly corresponds to the thickness of any of the parts which are defined before in dividing the sequence into the four parts. On the other hand, the curve of OD–2 does not possess such a trend of the sequence of the autocorrelation coefficients. The fact may indicate that the trends of sedimentary strength of the two parts (3) and (4) do not much resemble each other.

IV. Geological consideration

The trend of particle size changes in lake and bay sediments such as the Osaka Group is considered to reflect generally the relative expansion and contraction of sedimentary basins. Therefore, the trends showing a similar fluctuation to each other might represent a similar development of the basins.

It is recognized below the boundary C that the trend of SENRIYAMA is different from those OD–1 and OD–2 which resemble each other (Fig. 3). This seems to suggest that the movement of basin building in Senriyama region differed from that in the vicinity of the Osaka City at that time.

It is found between the boundaries A and C that all the trends show almost the same fluctuation. YOKOYAMA (1969), judging from the extensive distribution of the Osaka Group of this age and common occurrence of marine clay beds, has

* These horizons are according to the references in Tab. 1.

claimed that the sedimentary basin of the group expanded to its maximum in dimension during this stage. Hence, it is probable that the influence of local movement then was relatively so weakened and the trend in each location may have become to show the similar pattern.

The difference in the trends becomes conspicuous again above the boundary A. This may indicate that the sedimentary basin of the Osaka Group was not only contructing but also subdividing during this stage.

The alternation of marine clay beds and nonmarine beds has been considered to indicate the fluctuation of sea level caused by the climatic change of glacial and interglacial times.

The periodical oscillation recognized above the boundary B seems to suggest the periodical sea level changes. According to the result mentioned in the preceding chapter, it is reasonable to consider that the shortest one of its periods spans at least two marine clay beds. The period, however, could be shorter in reality when taking into consideration of the influence of the linear trend in the lower part. At the same time another interpretation is also possible; the marine regressions which had occurred twice between Ma 2 and Ma 3, and Ma 4 and Ma 5 might have been larger in scale than those between Ma 3 and Ma 4, and Ma 5 and Ma 6, since the particle size tends to be coarser in the beds which lie between Ma 2 and Ma 3, and Ma 4 and Ma 5.

In general the Osaka Group has been subdivided at Ma 3 into the two parts, the upper and the lower, using Azuki tuff in it as a key. However, the group could be divided at the vicinity of the boundary B, that is, at the upper boundary of Ma 2, based on the trends obtained by the present investigation.

V. Concluding remarks

As mentioned in the last chapter, it is evident that a definite pattern of trends exists in common with all the columns in the region, the Osaka Plain. The fact suggests that a definite sedimentary trend had been preserved in whole the basin through the development of the basin. Consequently, the general correlation among the columns can be carried out according to the pattern of the trends, although it is not much accurate because the influence of oscillative trends in the pattern is sometimes so intense that it is difficult to identify the pattern in detail. Therefore, two of the purposes, (2) and (3), mentioned in the first chapter, are considered to be almost attained. For the purpose (4), several useful suggestions contributing to the study of the history of the sedimentary environments are presented in the last chapter. Several working hypotheses are newly proposed based on the results of the investigation, in addition to the suggestions consistent with the facts derived from the previous works. Therefore, it is desired that much more data will be processed.

The way of processing and its computer program were designed in the study, referring to the method adopted by VISTELIUS (1967).

The assumed mean size was defined as a value of sedimentary strength which quantitatively indicates a certain aspect of sedimentation (see Chapter II). The procedure computing the value was designed so that the difference of sedimentary strength would be expressed as remarkably as possible, and that the computed values would be ranked in as appropriate order among the basic values. For an alternation of sand and silt, for example, the assumed mean size will be calculated as (12+0.5)/2, that is 6.25, assuming that the alternation consists of sand and clay with a propotion of one to one. The computed value, in this case, slightly exceeds the basic value of silt, 4.

This method might be considered to be very crude. However, the computed values obviously show an appropriate order of sedimentary strength together with four basic values, and, therefore, no serious problems could be found in so far as the recognition of the general trends of sedimentary strength is concerned. The validity of the argument may be proved by the existence of a definite pattern of trends common to all the columns. There is, however, no doubt about that any ranking of sedimentary strength with fixed values according to more complete, objective descriptions of lithology is much desirable for this kind of analysis.

VISTELIUS (1967) has set up those fixed values based on the objective and detailed standards for the descriptions of lithology. Since such standardized data, however, have not been available, the computation method described above was employed in the present study.

It may be concluded that 21 terms moving smoothing method is quite effective to find a general trend; the Fourier analysis is suitable to investigate the periodical trends; the run test is not adequate to examine the significance of accepting the trend obtained as a general one, but is efficient for avoiding the acceptance of any trend which is scarce of significance; and the autocorrelation analysis can show the presence or absence of periodicity and its period, if any.

Finally all the analyses, being combined and supplemented with each other, were proved to be able to systematically analyze the geological time sequencial data. And, they were all carried in the computer program designed in the present investigation. Hence, the purpose (1) is considered to have been attained.

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Center of Kyoto University*. (PRÕBLEM NO. 5001 CF 653)

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Appendix; Computer Program**

1) Contents and procedure

The five kinds of processings as described below are carried out by the program, and its processing flow is illustrated in Appendix-fig. 1.

(a) Convertion of column data to numeric ones.

(b) 5 and 21 terms moving smoothing.

(c) Fourier analysis.

(d) Run test.

(e) Autocorrelation analysis.

2) Inputs

An input data deck is formed as follows:

(a) Controle data for an option of processing and for designations of data kind*** and way of output.

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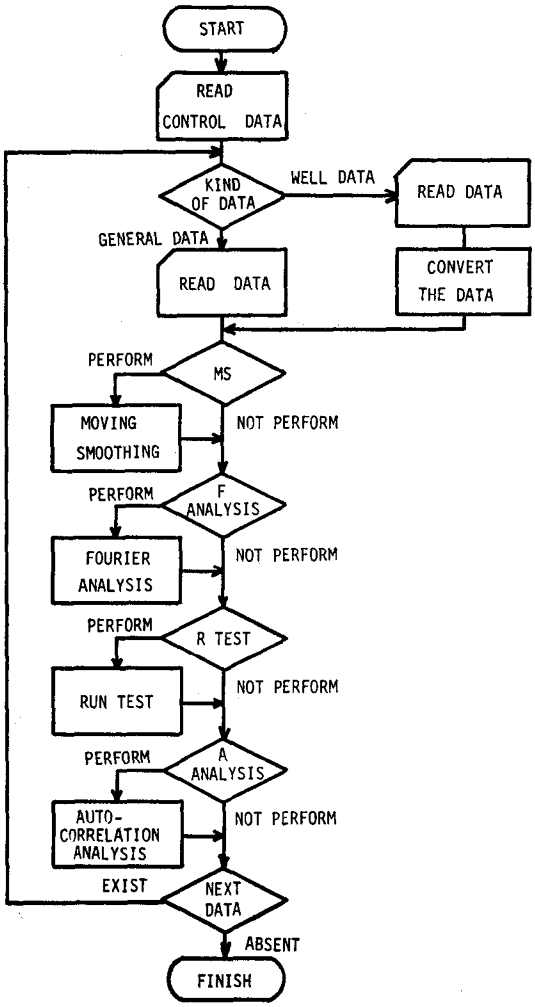
* FACOM230–75 system is available. The system corresponds to IBM360/195 system.

** See YAMAMOTO (1972) for more detail.

*** Two kinds of data can be processed; general and column ones.



Appendix-fig. 1. Process flowchart of computer program for time trend analysis.
MS: MOVING SMOOTHING
F: FOURIER
R: RUN A: ANALYSIS

(b) Sample source data.

i. General data: arranged in time wise.

ii. Column data: the no., upper boundary depth and litho-facies code*

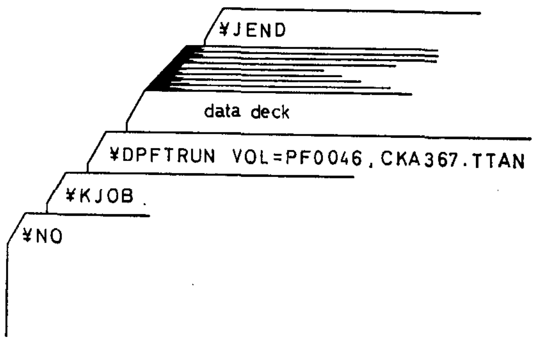
* A numerical code consists of four digits. The digits indicate gravel, sand, silt and clay propotions respectively. 25% of propotion makes a unity in the digit. For example, lithology of a sand and gravel bed is represented by a number 2200.

of each bed should be arranged in turn from the top of the column.
(c) A control datum for reporting the existence of following another set of data* to be processed.

3) Outputs
(a) Prints of input data.
(b) Results of the moving smoothings (graphically displayed).
(c) Results of the Fourier analysis; Fourier coefficients, power-spectrums and nonbiased variences (graphically displayed), and curves of Fourier series.
(d) A table resulted from the run test.
(e) Graphs resulted from the autocorrelation analysis.

4) Category for using the program

When the program stored in a public file (magnetic disk pack) of The Data Processing Center of Kyoto University are used, only such a card deck as in Appendix-fig. 2 is required to be prepared. ¥NO card** and ¥KJOB card are required for the informations of accepted and preferential turn and for the identification of the user respectively. ¥DPFTRUN card calls out the program stored in the file and starts it running. ¥JEND card indicates the end of the deck.



Appendix-fig. 2. Example of computer card setup for time trend analysis program.

* (a) is unnecessary in the following sets.
** These cards punched marks "¥" on the head correspond to JCL cards (Job Control cards) for IBM360.