The Korean Journal of Quaternary Research
Vol. 4, No. 1, 41~58 (1990)

Palaeoenvironmental Implication of the Quaternary Gravel Sequences on the Basis of Gravel Shape

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礫의 形態에 의한 第4紀 礫層準의 古環境的 考察

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ABSTRACT

Gravel shapes of the terrace gravel sequences are compared with the present river gravels and beach gravels in the Pohang and its surrounding areas. Seventeen gravel textural parameters are divided into 5 groups based on R-mode factor analysis. Among them, three parameters (RDm, MPSm, SZstd) are selected for a test of discriminant possibility of palaeoenvironment of the terrace gravel deposits. Marine gravels are in the range of 0.49 to 0.75 in mean roundness, 0.46 to 0.78 in mean maximum projection sphericity and 0.39 to 1.85 in standard deviation of size, whereas river gravels are 0.28 to 0.51 in mean roundness, 0.66 to 0.72 in mean maximum projection sphericity and 1.04 to 1.81 in standard deviation of size.

For practical access to the palaeoenvironment discrimination, a bivariant diagram between mean roundness and mean maximum projection sphericity is the most effective. The marine terrace gravels are plotted within the variation range of present beach gravels and show 0.49 to 0.71 in mean roundness and 0.59 to 0.66 in mean maximum projection sphericity. The gravels of river terrace vary within the range of gravels derived from present river bed and are characterized as 0.36 to 0.48 in mean roundness and 0.66 to 0.71 in mean maximum projection sphericity.

要 約

浦項 및 隣接地域에서 現河成礫과 現海濱礫에 비교하여 段丘礫層에 대한 礫의 形態硏究를 실시하였다. 礫의 組織變數 17개를 要因分析에 의해 5개 變數集

合體로 구분할 수 있다. 이 중에서 圓磨度平均値와 圓球度平均値 및 粒度의 標準偏差를 選定하여 段丘礫層의 古環境을 구분할 수 있다. 海濱礫의 경우, 圓磨度平均値가 0.49-0.75, 圓球度平均値가 0.46-0.78, 粒度의 標準偏差가 0.39-1.85의 범위로 나타나며, 반면에 河成礫의 경우, 圓磨度平均値가 0.28-0.51, 圓球度平均値가 0.66-0.72, 粒度의 標準偏差가 1.04-1.81의 범위로 각각 나타난다.

古環境을 실질적으로 簡便하게 判別하기 위하여 圓磨度平均値와 圓球度平均値를 이용한 2變數 도표를 이용하면 가장 효과적이다. 이 도표상에서 海成段丘礫은 現海濱礫의 分布範圍인 圓磨度平均値가 0.49-0.71, 圓球度平均値가 0.59-0.66의 範圍以內에 모두 포함된다. 한편, 河成段丘礫은 現河成礫의 分布範圍인 圓磨度平均値가 0.36-0.48, 圓球度平均値가 0.66-0.71의 범위 이내에 모두 포함된다.

INTRODUCTION

The generation of gravel shape is closely connected with the hydraudynamic process, lithology, transportation distance and so forth. The natural process is commonly not continnous, nor uniform in space and time so as to result in a various population of gravel shape. The inhomogeneous and anisotropic body of the gravel deposits produce various gravel shape population. This gravel shape has long been an object to study palaeoenvironment. However, the quantitative approach to unravelling the depositional process of gravel sequences has not been done so often in Korea.

The present beach in the southeast coast of the Korean Peninsula is wave-dominant beach. In the beach strips near the Umok-Yeonam coast and Gampo-Jeongjari coast, well-rounded pea gravels and disk-shaped gravels are both outnumbered than in the creeks or rivers along the Naengcheon valley. This is evidenced by the terrace gravels on the sea cliffs above the present beach strips or above the present river bed along the river valley.

It is assumed that the palaeo-base levels of terraces developed along the valley were existed at the higher altitude than present valley bottom. This phenomenon will be supported by comparing the terrace gravels with those on the present river bed in the Naengcheon valley. Furthermore terraces developed along the coastal strips at the higher altitude than the present mean sea level can be assumed to have been formed either near the present sea level or at the higher base-level. But, it is prerequisite that theae terrace gravels must have been derived from the beach, specifically from backshore-foreshore area.

The study of gravel shape population is necessary in this area because any fossil skeleton was not found and also because the main constituents of terrace deposits are gravels and sands. The sandy deposits and fine-grained deposits can not commonly indicate their palaeoenvironment without eliminating secondary elements which were produced by the disintegration of fine particles in the process of climatogenic weathering or alterating in place.

The main purpose of this paper is finding out the most appropriate parameters among 17 parameters representing gravel shapes in order to provide discriminant criteria between the terrace gravel populations derived from valley side or hillslope and those from the sea cliffs by comparing with the present counterparts ranging from upstream valley through river mouth to beach.

STUDY AREA

Geology of the study areas are composed of 8 main stratigraphic sequences on the basis of unconformity (Fig. 1). The pre-Quaternary basement sequences include Cretaceous fluviolacustrine deposits (Crl-sequence), Paleogene volcanic and plutonic rocks (Tp1- and Tp2-sequences), and Neogene volcanic and sedimentary rocks (Tnl-, Tn21-, Tn22-, and Tn3-sequences). The Yeonil Basalt (Tateiwa, 1924) was previously mapped as Quaternary volcanic rocks, but it turned out as Neogene volcanic rocks constituting Tnl-sequence based on K-Ar dating (Jin et al., 1988, 1989; Tamanyu, 1985). Quaternary sequences show typical Pleistocene terraces (Qp-sequence) and Holocene alluvium (Qh-sequence) along the coastal cliffs or in both sides of river valley. The study area covers the paired terraces along the Naengcheon valley (NV) in Pohang area, terraces along Umok-Yeonam (UY) coast in nothern Pohang area and Gampo-Jeongjari (GJ)

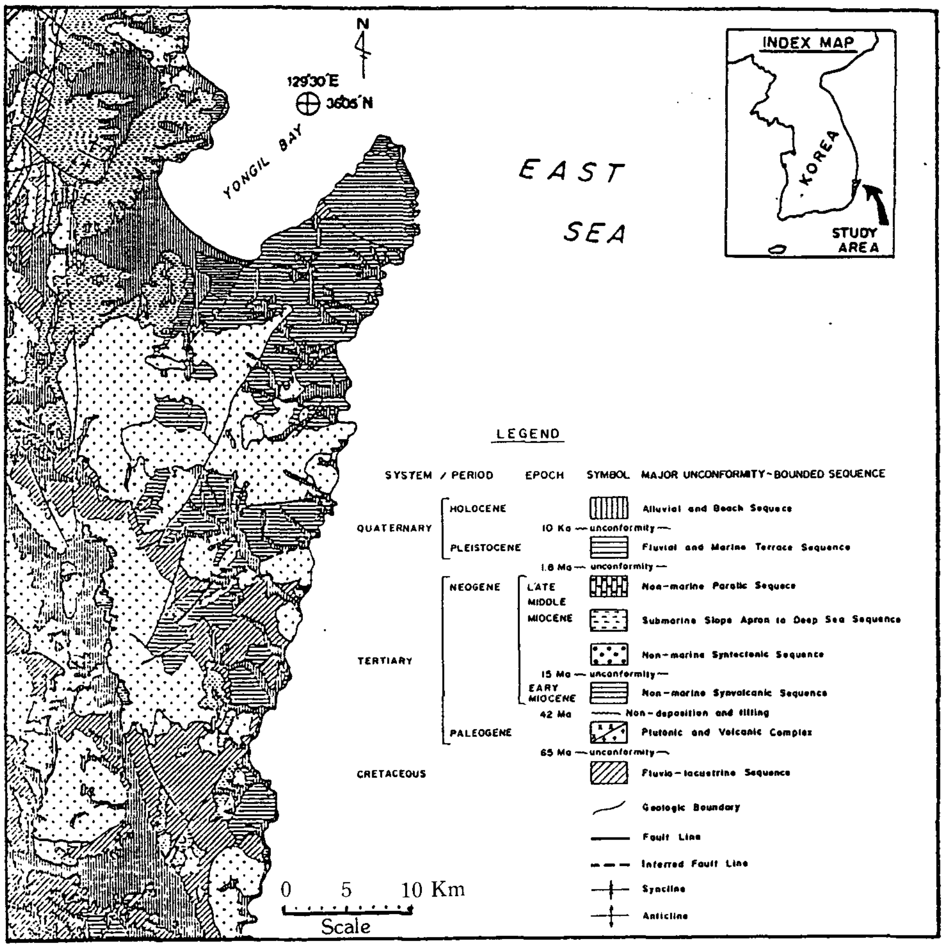
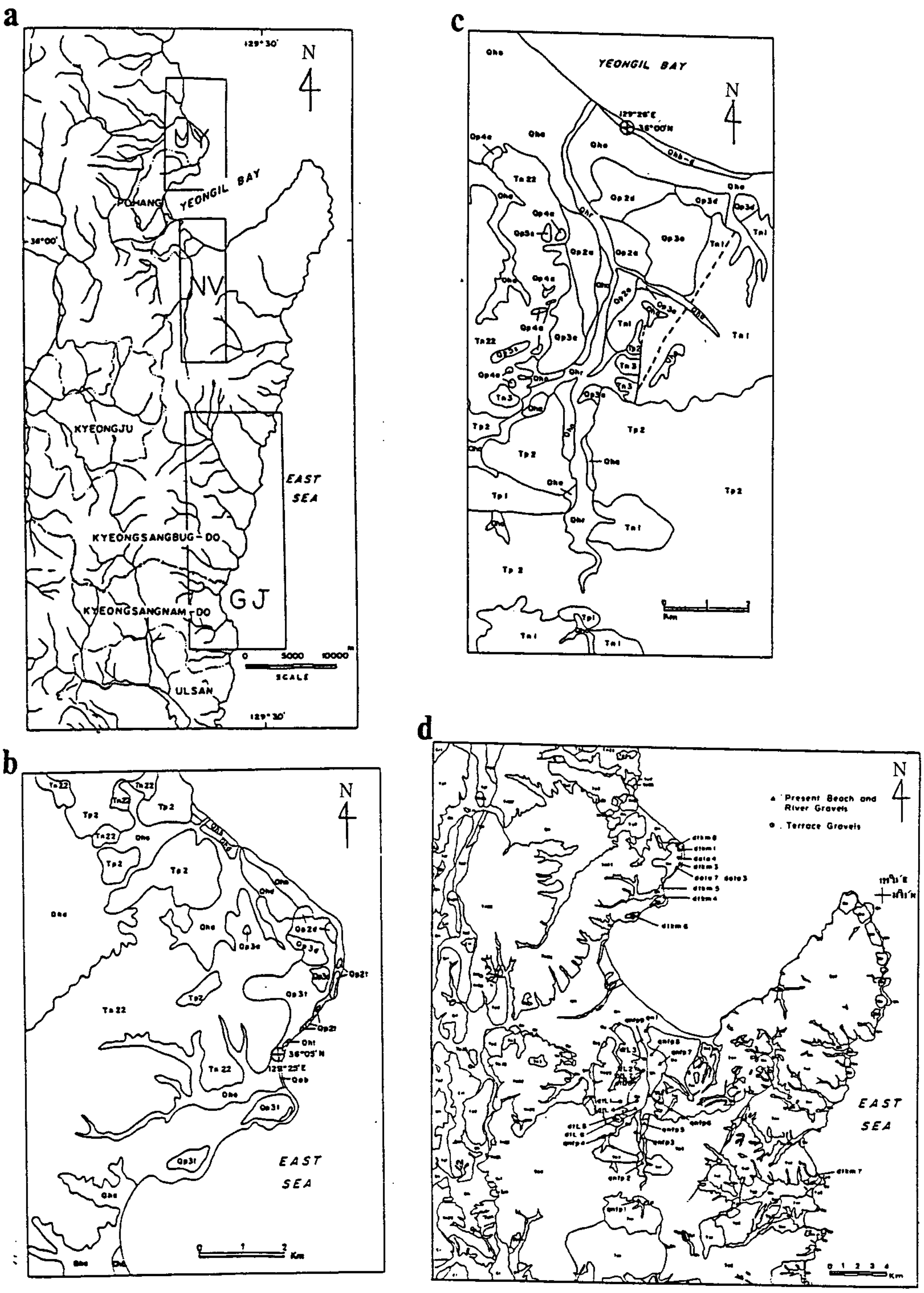


Fig. 1. Geology of the Pohang area. Stratigraphic units are grouped by major unconformity-bounded sequences (modifed after various sources: Kim et al., 1968; Tateiwa, 1924; Um et al., 1964; Yoon, 1989; Yun, 1986).


a
b
c
d
N
YEONGIL BAY
POHANG
KYEONGJU
EAST SEA
KYEONGSANGBUG-DO
KYEONGSANGNAM-DO
ULSAN
NV
GJ
SCALE
Km
Present Beach and River Gravels
Terrace Gravels

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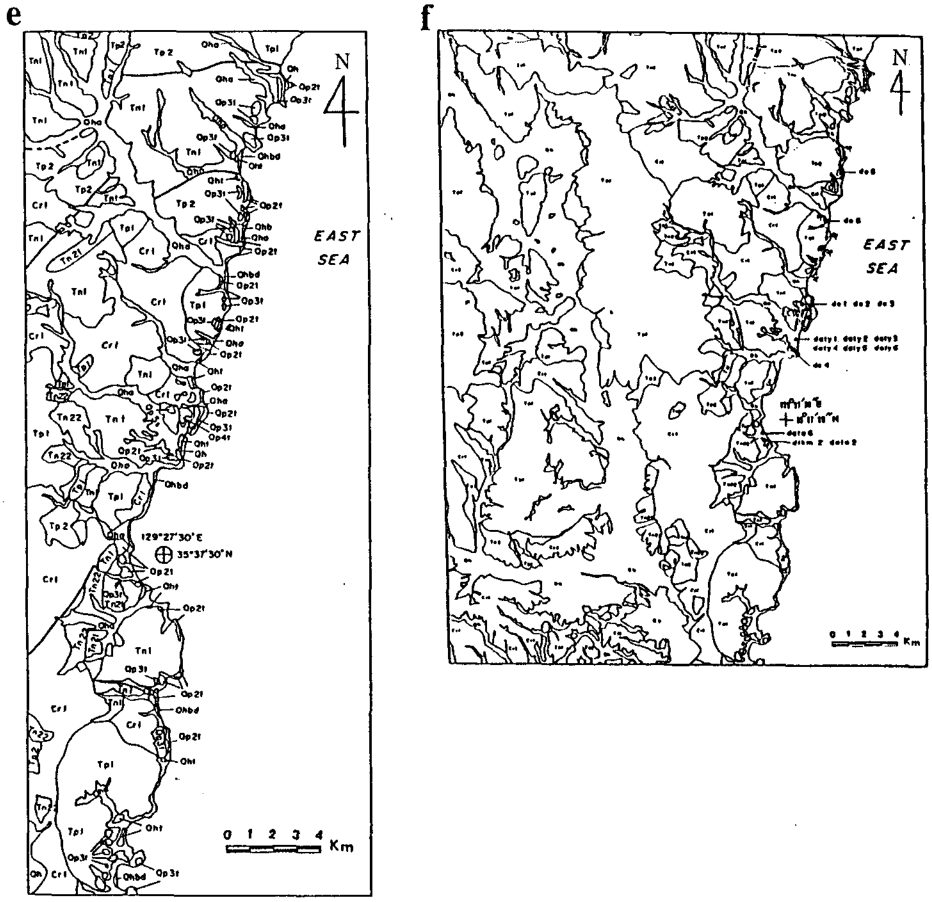

Fig. 2. Quaternary site geological maps and sampling locations of gravels: (a) sites for gravel study, Umok-Yeonam (UY) area, Naengcheon valley (NV), and Gampo-jeongjari (GJ); (b) Quaternary geological map of UY-site; (c) Quaternary geological map of NV-site; (d) sampling locations of UY- and NV-sites; (e) Quaternary geological map of GJ-site; (f) sampling locations of GJ-site.

* Legend of lithology in geology maps: Crl, Cretaceous tuffaceous sandstone, shale and hornfels; Tpl, Paleogene granite; Tp2, Paleogene ryolitic to dacitic ignimbrite and tuff; Tn1, Neogene non-marine tuffaceous gravelstone, sandstone and mudstone with alternations of volcaniclastic rocks; Tn21, Neogene non-marine marginal gravelstone; Tn22, Neogene marine mudstone with sandstone and gravelstone; Tn3, upper Neogene non-marine sandstone and mudstone with lignite and gravelstone; Qp5s, 5th strath terrace and erosional palaeo-surface; Qp4t, 4th terrace gravels on the coastal fringe; Qp4a, 4th palaeo-valley fills with gravels; Qp3t, 3rd terrace gravels on the coastal fringe; Qp3a, 3rd paleo-valley fills with gravel and sand; Qp3d, fine to medium palaeo-dune sand with secondary interstitial clay-fills; Qp2t, 2nd terrace gravels with gravel and sand; Qp2a, 2nd palao-valley fills with gravel and sand; Qp2d, well sorted fine to medium palaeo-dune sand; Qht, 1st terrace gravels with well sorted fresh gravels; Qha, 1st palaeo-valley fills or alluvium with unsorted gravelly sands and lenses of silty clays; Qhd, well sorted present dune sand; Qhb present beach gravel and sand; Qhbd, undifferentiated beach sand and dune sand.

coast in southern Pohang area (Fig. 2a).

The Quaternary Qp-sequence unconformably overlies the erosional surface of the pre-Quaternary deposits and volcanic rocks. The Quaternary sequences are characterized by the beach deposits, alluvium in the valleys and diluvium along the fringe of hills or sea cliffs. Beach sands and gravels are commonly exposed on the berm or shoreface. The alluvium and diluvium crop out along the present rivers and paleo-valleys toward the upstream.

The alluvium (Qhr) consists of poorly sorted gravels and sands. The diluvium are commonly indicating either terrace deposits, or valley fills, or colluvial deposits above several or tens of meters of the present watercourse or valley. Dune sands (Qhd) are well developed above the beach deposits (Qhb) in Pohang area. Above the sea cliff or coastal hills there are well sorted pebbles to cobbles which are also distributed in the pattern of stepwise terraces. Paleo-dune sands are observed on these terraces.

Marine terraces had been identified along Umok-Yeonam coast (Kanehara, 1936; Yoon, 1975) in the northern part of Pohang city and these were classified into three levels (Jo, 1978), I-surface (45-50m), II-surface (30-35m) and III-surface (10-20m), on the basis of the altitudes of continued abrasion platforms cut into the Tertiary mudstone.

Along the southeastern coastal area, marine terraces were studied by various geoscientists. Six marine terraces were firstly defined at about 20 meter intervals by Kim (1973). Oh (1977) introduced one Holocene and three Pleistocene terraces along the coast from Janggigok to Dangweol and classified them into High terrace (Gampo surface; 60-80m), Middle terrace (Seakcheonri surface; 30-50m), Lower terrace (Sanhari surface; 10-20m) and Holocene terrace and beach ridges (1-3m). CANATOM (1977, 1978, 1979, 1980 and 1981), however, reported that the Pohang-Yangsan block has a succession of marine terraces, Lower Terrace (5m), Middle Terrace (20m) and Upper Terrace (45m), along the east coast of Korea.

From the geologic maps (Fig. 2b, 2e), Umok-Yeonam coast and Gampo-Jeongjari coast show gravel sequences developed at least on three different altitudes, 2-4m (First Terrace, Qht), 10-15m (second Terrace, Qp2t) and 35-42m (Third Terrace, Qp3t) above sea level (Fig. 3a, 3c). The fouth terrace (Qp4t) and fifth terrace (Qp5s) do not have any significant sequences but show only erosional surface with the exception of some gravel fragments.

Quaternary terrace deposits in the Naengcheon valley were initially mapped as Diluvium by Tateiwa (1924). Jo (1978) divided the terraces of Naengcheon valley into three different levels, I-surface, II-surface and III-surface. The I-surface is located at about 15 meters in the upstream area and at about 8 meters in the downstream area above the present floodplain. The III-surface is distributed at about 4-5 meters above the present floodplain and is occasionally submerged below the present alluvium. The II-surface does not show a great difference in elevation from the I-surface and is also submerged below the III-surface or the alluvium. According to Lee and others (1989, 1990), Naengcheon valley is extending from Indeok through Ocheon-eup to Yongsan villages at which terrace gravel sequences are successively developed along both sides of the valley as shown on the transverse profiles of Fig. 3b.

Five terraces are identified on the basis of aerial photography, levelling and detailed field mapping from the Naengcheon river bottom (Table 1). Gravel sequences are found in the four terraces. From the geologic map (Fig. 2c), it is confirmed that the relative elevations of the terraces are remarkably consistent across the

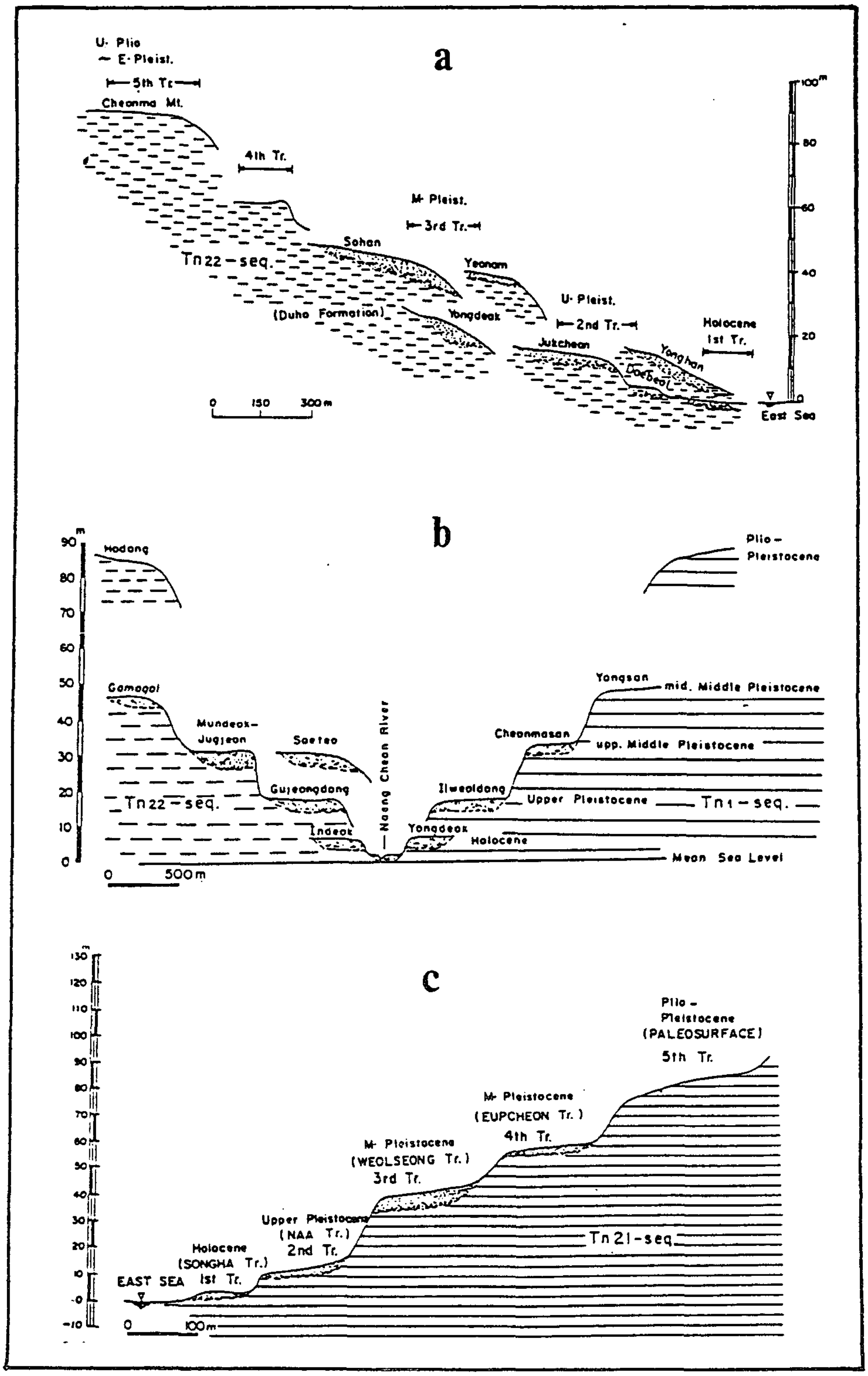

Fig. 3. Representative transversal sections of the gravel terrace sequences of (a) UY site in Fig. 2b, (b) NV site in Fig. 2c, and (c) GJ site in Fig. 2e.

Table 1. Characteristics of five terraces developed in the Naengcheon valley.

Terrace Sequence	Type Locality	Elevation from River Floor	Terrace Type
Terrace I	Indeok	3 - 4m	Fill
Terrace II	Gujeong	10 - 12m	Fill
Terrace III	Mundeok	25 - 30m	Fill
Terrace IV	Gamagol	40 - 45m	Fill / Rock Cut
Terrace V	Hodong	80 - 90m	Rock Cut

width of the valley. The altitude of the Naengcheon paired terraces is systematically increased from the present river bed. The First Terrace (Qha) is extending on the level of 3-4m, the Secnd Terrace (Qh2a) on the level of 10-12m, the Third Terrace (Qh3a) on the level of 25-30m, the Fourth Terrace (Qh4a) on the level of 40-50m and Fifth Terrace as erosional surface (Qp5s) at the level of 80-90m above the present river bed, respectively (Fig. 3b).

The Quaternary terrace stratigraphy in the Naengcheon valley and Umok-Yeonam coastal area and Gampo-Jeongjari coastal area was established in conjunction with terrace deposits and fluctuation of the base level (Lee, 1985, 1987; Lee et al., 1989, 1990; Kim, 1990). These terrace study has resulted that the age of the terrace sequences are after the Middle to Upper Middle Pleistocene.

PROCEDURE OF GRAVEL SHAPE ANALYSIS

The gravel shape-size analysis was employed for a number of gravel samples from the Pohang area. The gravel samples were obtained from three Quaternary mapping sites (Fig. 2a). They are primarily composed of the terrace gravels, present river bottom and beach gravels. From river mouth toward the upstream, the gravel deposits were sampled not only at the present beach and valley floors, but also at the stepwise terrace deposits. Gravel samples were collected randomly in order to avoid the chance of significant bias. The individual gravel samples were controlled by several sample groups in accordance with the altitudes of occurrence and the facies similar either to the present beaches or to river gravels. Special care was taken to differentiate the terrace gravels distributed along the hillslope or valley sides from the terrace gravels occurred along the coastal fringes. The Neogene gravels can be distinguished from the Quaternary gravels in the degree of consolidation, weathering, lateral continuity and thickness in the outcrops. The sampling locations of the gravels are shown on the location maps (Fig. 2d, 2f).

To determine gravel texture, the length of three orthogonal gravel axes were measured at a precision order of 0.005cm to calculate roundness, size and sphericity parameters. The size parameter of gravels was obtained by measuring the longest dimension in each grain. Roundness parameter, Dk/Di, was based on the actual measurements of the smallest (Dk) and largest (Di) inscribed diameters at the edges of gravel. The radii of the curvature were measured with a nest of concentric circles duplicated on transparent plastic films. Circles are spaced at millimeter intervals with some supplementary circles marked on the sides of the plastic film. The basic assumption in this measurement is that the curvature of the sharpest single corner reflects the amount of rounding process experienced by the latest environment, and it is not the results of the inherited roundness from other environments. As other quantitative methods for gravel roundness, Dk/L (Wentworth, 1922; Cailleux, 1945), ((Dk+ ... +Dc)/n)/Di(Wadell, 1932) and Dk/I (Kuenen, 1956) may be adopted. However, Dk/Di and Dk/I do not make much difference because the diameter of the inscribed circle is virtually the same as that of the intermediate axis.

There are many sphericity parameters but in this study Maximum Projection Sphericity (MPS) (Sneed and Folk, 1958) is finally adopted because it is best representing the actual hydraudynamic condition (Dobkins and Folk, 1970). The MPS can be calculated by triple root of (S×S)/(L×I). The MPS compares the maximum projection area of a pebble with the maximum projection area of a sphere of the same volume. The MPS was defined as a reciprocal of "portance index" by Rosfelder (1960) in which he defines as "the ratio of the maximum cross-sectional area of the reference ellipsoid to the cross-sectional area of the nominal sphere".

In order to compare two groups of frequency distribution it is necessary to obtain descriptive statistical measures of the textural parameters which can give an information about the unimodal versus bimodal populations, and symmetrical versus non-symmetrical populations. For an input data of statistic measures, gravel dimensions of (1) long axis (2) medium axis (3) short axis (4) diameter of inscribed circle at the sharpest corner and (5) diameter of inscribed circle at the largest plane were used. Six statistical measures, including mean, variation, standard deviation, maximum error of precision, skewness and kurtosis, were calculated for 17 textural parameters. The 17 parameters include: (1) mean roundness (RDm) (Dobkins and Folk, 1970), (2) standared deviation of roundness (RDstd), (3) mean maximum projection sphericity (MPSm) (Sneed and Folk, 1958), (4) standard deviation of size (SZstd), (5) mean size (SZm) (length equivalent to long axis), (6) skewness of size (SZsk), (7) kurtosis of size (SZkt), (8) mean flatness index (FLm) (Wentworth, 1922; Cailleux, 1945), (9) standard deviation of flatness index (FLstd), (10) mean of Y-axis ratio of binary form class diagram (Zingg, 1935), (11) mean of X-axis ratio of binary form class diagram (Zingg, 1935), (12) mean form ratio (FRm) (Sneed and Folk, 1958), (13) mean Oblate-Prolte Index (OPm) (Dobkins and Folk, 1970), (14) Lee's Index (Ml) (firstly used by Lee (1985)), (15) standard deviation of maximum projection sphericity (MPSstd), (16) mean Y-axis ratio of triangular form class diagram (S/L) (Sneed and Folk, 1958) and (17) mean X-axis ratio of triangular form class diagram ((L-I)/(L-S)) (Sneed and Folk, 1958).

The 17 textural parameters were tested by R-mode factor analysis in order to find out associations among different parameters. Four principal components (F1, F2, F3, F4) were applied and respective factor loadings for 43 samples were obtained (Table 2).

DATA INTERPRETATION

Five groups of associations of gravel parameters are obtained from the factor analysis, and the five groups include (A) MPSm-OPm- Ml- S/L- S/I- (L-I)/(L-S), (B) SZm-SZstd-I/L, (C) RDm- SZsk- SZkt, (D) RDstd- FRm-FLm- FLstd and (E) MPSstd (Fig. 4). Any parameters in group (A), group (B), group (C) and group (D) tend to be positively correlated with other parameters in the same group. As an illustration, the MPSm in group (A) shows positive correlation with any other parameters in the same group (A) because the parameters like OPm, Ml, S/L, S/I, or (L-I)/(L-S) have high Fl-loads ranging from 0.65 to 0.96 (Table 2). As

Table 2. Factor loadings of four principal components (F1, F2, F3, F4) with respect to 17 shape parameters. 43 Quaternary gravel samples were used for R-mode factor analysis.

DESIGNATION OF VARIABLES		FACTORS			
		F1	F2	F3	F4
1	RDm	-0.58	-0.40	0.35	-0.11
2	RDstd	-0.36	0.00	-0.40	-0.13
3	MPSm	0.96	-0.20	0.08	-0.11
4	SZstd	0.34	0.49	-0.37	0.66
5	SZm	0.47	0.34	-0.52	0.54
6	SZsk	-0.47	0.16	0.72	0.35
7	SZkt	-0.37	0.02	0.75	0.33
8	FLm	-0.91	0.32	-0.14	-0.07
9	FLstd	-0.64	0.39	-0.21	-0.45
10	I/L	0.50	-0.82	-0.15	0.01
11	S/I	0.97	-0.05	0.11	-0.13
12	FRm	-0.69	-0.59	-0.30	0.17
13	OPm	0.73	0.58	0.27	-0.09
14	M1	0.94	-0.28	0.06	-0.09
15	MPSstd	-0.10	0.55	-0.12	-0.43
16	S/L	0.94	-0.24	0.06	-0.11
17	(L-I)/(L-S)	0.65	0.67	0.22	-0.15

the same rule is applicable to other parameters belonging to other groups, it is clear that the parameters belonging to the same group are positively correlated from one after another. On the other hand, the parameters having nearly same value but opposite sign in terms of F1-loads or F3-loads are negatively correlated from one after another. For example, the parameter, MPSm, belonging to group (A) is negatively correlated with the parameter, FLm, belonging to group (D) because both parameters have nearly same F1-loads, but different signs (MPSm = +0.96 vs. FLm = -0.91) (Fig. 4; Table 2).

For the purpose of adequately selecting some independent parameters applicable for a palaeoenvironmental discrimination, those parameters correlated one after another must be discraded. Although it is true to get as many combinations as possible to differentiate the depositional environmnet, three fundamentally important parameters are selected for discriminating palaeoenvironments. Three parameters selected from group (A), group (B) and group (C) were most suitable for the purpose. Three parameters are mean maximum projection sphericity (MPSm) from group (A), standard deviation of size (SZstd) from group (B) and mean roundness from (RDm) group (C). A 3-dimensional diagram is drawn on the basis of three parameters having numerical values of 43 samples (Table 3). Two typical depositional environments are discernible on the diagram (Fig. 5).

The relations of three fundamental parameters with the depositional environments are explained in terms of their hyraudynamic implications. The high value of size parameter,

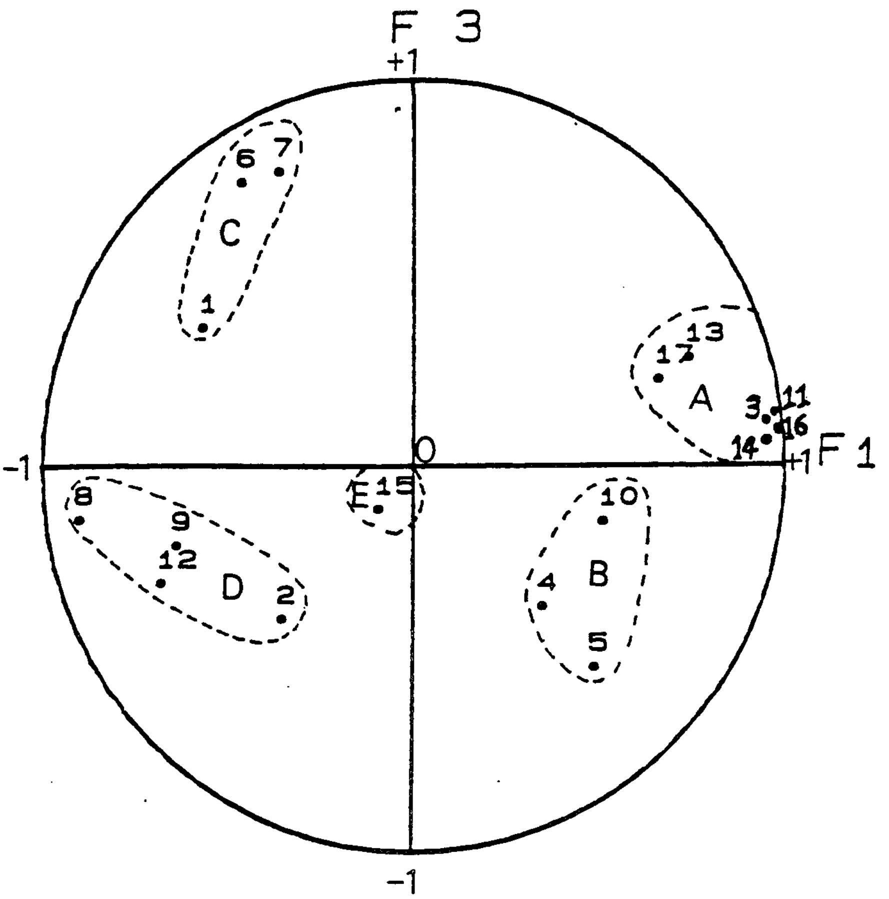

Fig. 4. Bivariant diagram plotted between F1-principal factor and F3-principal factor reveals five groups of the associations of gravel textural parameters. Five groups of associations include (A) MPSm-OPm-(L-I)/(L-S)-S/I-MI-S/L, (B) SZstd-SZm-I/L, (C) RDm-SZsk-SZkt, (D) RDstd-FLm-FLstd-FRm, and (E) MPSstd.

SZstd, is found in the beach gravels (ranging from 0.39 to 1.85) as well as river gravels (ranging from 1.04 to 1.81), but average of the SZstd is smaller in the beach gravels than in the river gravels. This is due to different wave regime between berm and foreshore of the beach. On berm, pea gravels are infilled in among the pebbles and cobbles, but in the foreshore, the backwash to swash motion of wave action favors to select equidimensional gravels easy to be tracted or saltated. The highest value of the SZstd are therefore related to the berm deposits rather than foreshore deposits in the beach environment. The rolling or sliding motion prevalent in the river current, however, increase SZstd even higher than the value in the swash zone of beach.

The roundness parameter, RDm, is differentiated clearly between river gravels and beach gravels (Fig. 5). The beach gravels show higher RDm (0.49-0.75) than the river gravels (0.28-0.51). This is due to continuous wave action in the beach environment, favoring for motions of rolling, sliding or creeping on the surfaces of subjacent gravels which result in an effective abrasion of gravel edges.

The sphericity parameter, MPSm, varies more widely in the beach environment (0.46-

Table 3. Mean roundness (RDm), mean maximum projection sphericity (MPSm) and standard deviation of size (SZstd) of present beach, present river bed gravels, and terrace gravels.

Gravels	Sample Name	Mean Roundness	Mean MPS	Size Standard Deviation
Janggi-Jeongja Present Beach (YPB)	daty1	0.542	0.668	0.451
	daty2	0.625	0.781	0.834
	daty3	0.608	0.670	0.804
	daty4	0.578	0.636	0.725
	daty5	0.595	0.650	0.862
	daty6	0.632	0.582	0.388
	data6	0.753	0.513	0.923
	dtkm7	0.544	0.638	1.116
Umok-Yeonam Present Beach (UPB)	data3	0.541	0.539	1.517
	data7	0.600	0.462	0.487
	dtkm3	0.488	0.463	0.910
	dtkm4	0.540	0.500	1.447
	dtkm5	0.530	0.637	1.397
Naengcheon Present River (NPR)	qnfp1	0.301	0.671	1.512
	qnfp2	0.284	0.696	1.323
	qnfp3	0.406	0.715	1.327
	qnfp4	0.364	0.692	1.176
	qnfp5	0.335	0.697	1.474
	qnfp6	0.431	0.709	1.300
	qnfp7	0.464	0.677	1.041
	qnfp8	0.506	0.715	1.102
	qnfp9	0.464	0.694	1.102
	dtL5	0.307	0.683	1.421
Eupcheon 1st Terrace (Ytr1)	de6	0.615	0.610	0.802
Gamo-Jeongja 2nd Terrace (Ytr2)	data2	0.707	0.598	1.251
	de5	0.599	0.613	0.746
	de4	0.627	0.653	1.199
	dtkm2	0.598	0.651	0.335
Gampo-Jeongja 3rd Terrace (Ytr3)	de1	0.634	0.634	0.223
	de2	0.659	0.621	0.414
	de3	0.649	0.659	1.002
Umok-Yeonam 2nd Terrace (Utr2)	data4	0.654	0.619	1.486
	dtkm1	0.487	0.591	1.845
	dtkm8	0.536	0.603	1.711
Umok 3rd Terrace (Utr3)	dtkm6	0.637	0.623	1.143

Table 3. Continued

Gravels	Sample Name	Mean Roundness	Mean MPS	Size Standard Deviation
Naengcheon 1st Terrace	dtL4	0.356	0.689	1.448
(Ntr1)	qn1	0.417	0.683	0.806
Naengcheon 2nd Terrace (Ntr2)	dtL3	0.387	0.705	1.238
Naengcheon 3rd Terrace	dtL2	0.439	0.680	1.280
(Ntr3)	dtL7	0.466	0.670	1.805
	dtL8	0.399	0.655	1.592
Naengcheon 4th Terrace	dtL1	0.415	0.699	1.670
(Ntr4)	dtL6	0.476	0.697	1.270

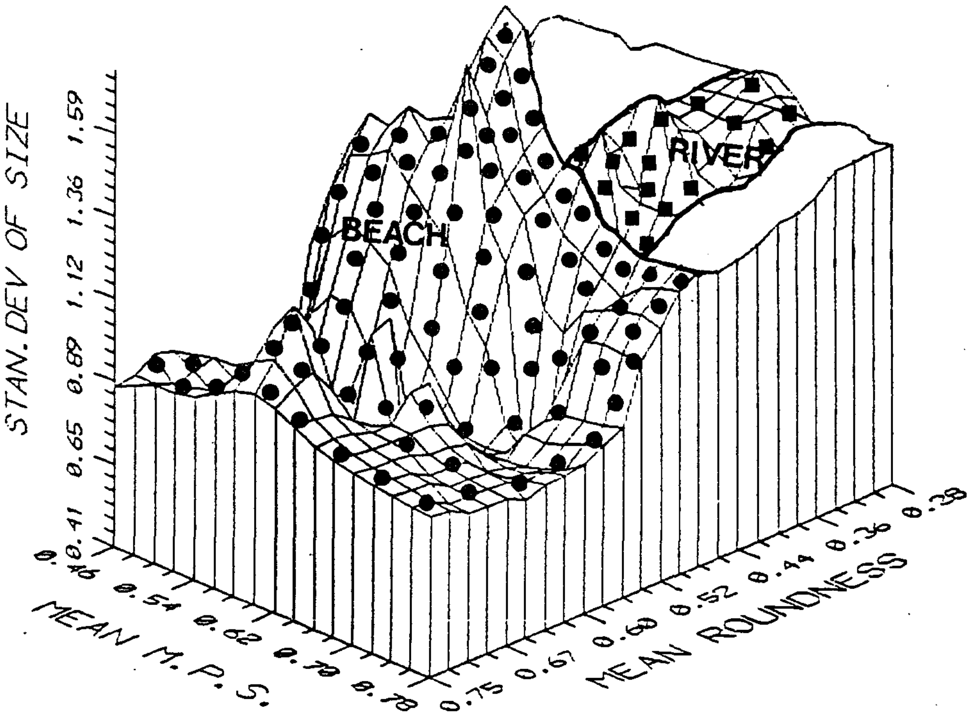

Fig. 5. 3-D topographical diagram drawn by three gravel shape parametes. RDm parameter as X-axis, MPSm parameter as Y-axis and SZstd parameter as Z-axis. Beach gravels and river gravels are discriminated on this diagram.

0.78) than in the river environment (0.66-0.72). The MPSm is higher in the foreshore than in the backshore because of the predominance of the rolling and sliding motion in the swash zone.

River favors for a rleatively discontinuous and unidirectional current regime and an occasional turbulence or torrential flow regime. This increases tractive and saltatory motions of gravel paticles and concentrates equant or prolate gravel particles associated with relatively poorly sorted gravel size populations. The beach environment, as indicated binary or triangular form classes (Table 4), is represented as an increasing number of oblate to blade population of gravel shape. The increase of platy form can be explained by a selective shape-sorting process in the backshore.

In this study it is possible to isolate the shape population of each individual gravel sample quantitatively in a simple way. The bivariant

Table 4. Percentile distribution of form classes representative of 4 groups of gravel sequences, present river deposits, present beach deposits, river terrace deposits and marine terrace deposits.

Deposits \ Form Classes	Total No.	Sneed and Folk (1958)										Zingg (1935)			
		C	CP	CB	CE	P	B	E	VP	VB	VE	OB	SP	BL	PR
Present River	841	5.6	10.1	19.6	13.4	11.7	25.4	9.4	0.7	2.7	1.3	36.3	36.9	10.5	16.4
Present Beach	3,557	3.2	5.1	9.6	6.6	11.6	23.9	7.5	8.4	20.0	4.1	46.0	17.8	25.3	10.9
River Terrace	1,973	5.8	8.3	15.4	12.6	9.4	25.3	14.2	1.6	5.3	2.2	36.6	29.2	12.7	21.5
Marine Terrace	3,839	3.2	7.8	14.8	7.3	15.3	31.2	8.8	2.4	7.5	1.8	49.7	23.1	15.1	12.1

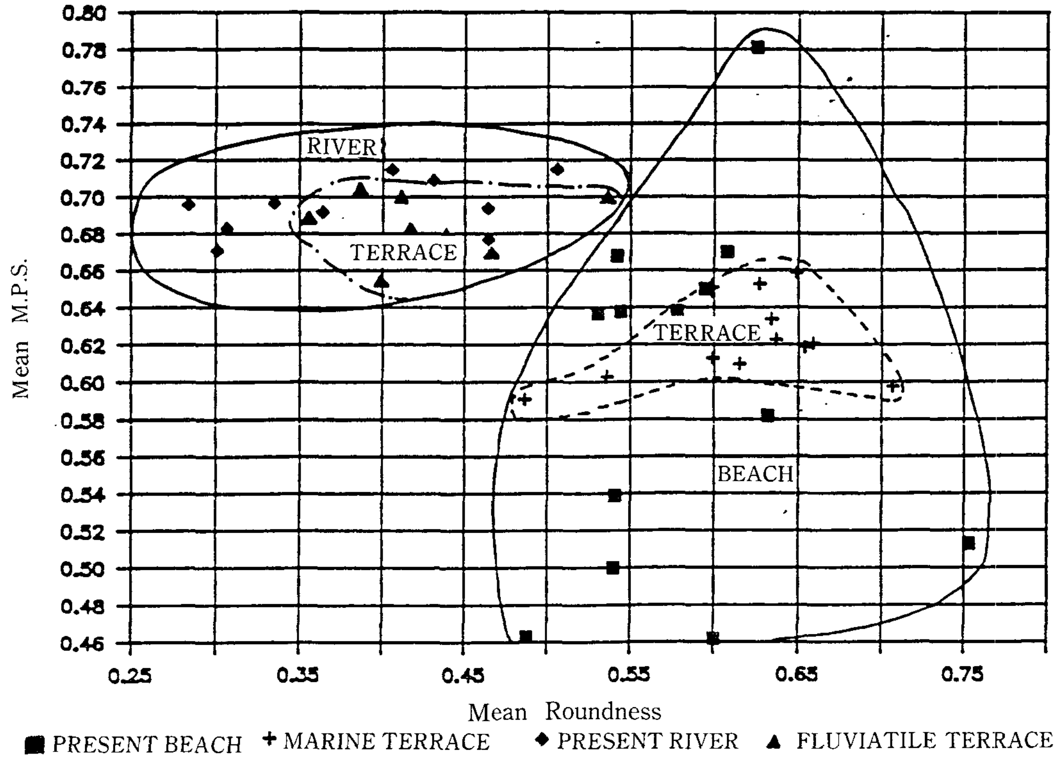

Fig. 6. Two groups of terrace gravel sequences are identified in the bivariant diagram between RDm- and MPSm-parameters. Terrace gravels plotted on the beach area are derived from marine terrace and terrace gravels plotted on the river area derived from fluviatile terrace.

combination of gravel shape parameters between RDm and MPSm provide an effective discrimination of the palaeoenvironment of gravel sequences (Fig. 6). The terrace gravels are bipartited based on this diagram which was initially suggested as a useful criteria between river and beach by Dobkins and Folk's (1970) research of the Tahiti-Nui Island, and attempted by Huh (1990) to interprete palaeoenvironment of Silla Conglomerate in Daegu area.

In addition, percentiles of 4 form classes (Zingg, 1935) and percentiles of 10 form classes (Sneed and Folk, 1958; Folk, 1968) are used for their discriminant characters between river gravels and beach gravels (Table 4). The percentage of oblate form of the beach gravels is higher than that of the river gravels by 10 to 13 per cent as shown in the bivariant form classes. The sum of very platy (VP) and very blade (VB) is higher in beach gravels (9.9-28.4 per cent) than in river gravels (3.4-6.9 per cent) in the triangular form classes.

The origin of gravel shape were experimentally examined in the laboratory and was reported to have a close connection between individual gravel shape and particle motion (Kuenen, 1942, 1956; Krumbein, 1941a, 1941b). The implicit assumption is that the shapes of gravel particles are not mainly controlled by the difference of lithology because the major lithology of the study area are volcanic rocks and tuffs, but the difference of hyraudynamic regime, mainly current or wave processes, causes shape segregation. The shape parameters of gravels are dealted with in two different environmental contexts, river or beach, on this ground. Hydraudynamically it is proved that the correlation coefficients in regard to MPS versus settling velocity and MPS versus rolling velocity are +0.97 and +0.86, respectively (sneed and Folk, 1958). This means that the higher the MPSm is, the higher rolling velocity the gravels have during tractive motion, and the higher settling velocity the gravels have during saltatory motion.

A wave-dominant hydraudynamic regime of beach environment is favored for selecting spherical particles having high MPSm which tend to moving back and forth or sliding on the beachface. The unidirectionally moving prolate to spherical particles are actually outnumbered in the current-dominant regime like in the river environment. The origin of gravel shape is often dealt with in two fundamentally different aspects: one puts more emphasis on the effects of gravel particle wearing, the other stresses on the effects of shape sorting process. The evidences that the shape population of river gravels in this study are controlled by a combined effects of saltation and traction (like rolling, sliding) (Moss, 1962, 1963), accompanied by an occasional torrential flooding, are illustrated as narrow range of high MPSm, uniformly high SZstd and conspicuously low RDm. The beach gravels in this study are dominated either by rolling-sliding-surface creeping (or shuffling) effects (Bluck, 1967) of swash-backwash movement in the foreshore zone, or selective shape sorting process (Dobkins and Folk, 1970) in the backshore. The bimodality of beach gravel populations is supported partly by bimodal size population like SZstd, and partly by sphericity population like MPSm.

CONCLUSIONS

In this study the mean maximum projection sphericity, mean roundness and standard deviation size of terrace gravels are selected for the most representative parameters for illucidating the palaeoenvironment of Quaternary gravel sequences. Among these three parameters, the mean maximum projection sphericity and mean roundness are both practical and useful to discriminate between river and beach gravels. The bivariant diagram between these two parameters is most effective to separate the present river gravels from the present beach gravels because beach gravels tend to have not only a wide range of mean maximum projection sphericity, but also higher mean roundness than about 0.50 in the Umok-Yeonam coast and Gampo-Yangnam coast.

The bivariant diagram is applied to the terrace gravels. The terrace gravels derived from the hillslopes or valley sides of the Naengcheon valley are plotted in the river environment, while those from the coastal fringes or on the sea cliff of the coastal hills above the present shoreline are in the beach environment. In short, the first, second third and fourth terraces along the Naengcheon valey are all fluviatile terraces in origin. On the other hand, first terrace near Epcheon village, second or third terraces occurred from Gampo-Jeongja coast to Umok-Yeonam coast are designated as marine terrace in origin.

The shape populations of beach gravels can be differentiated hydraudynamically from those of river gravels. The beach gravels have either directly undergone through rolling-sliding-surface creeping (shuffling) motion of swash-backwash flow in the foreshore zone, or indirectly selected platy-shaped particles due to relative immobility of platy gravels when they are once transported into the backshore (lag-effect). The beach gravels are characterized with two different groups of gravel size population, various groups in MPS-population, and a group of typically high roundness population. The river gravels are controlled by combined effects of saltation and traction (like rolling or sliding) due to current drives of turbulent flow. These regimes give rise to increasing the population of spherical to prolate forms of gravels, high variation of gravel size, and low chance of continuous abrasion among gravel particles.

REFERENCES

Bluck, B.J., 1967. Sedimentation of beach gravels: Examples from South Wales. Jour. Sed. Petrol., **37:** 128-156.

Cailleux, A., 1945. Distinction des galets marins et fluviatiles. Bull. Soc. Geol. France, **5**(13): 125-138.

CANATOM, 1977, 1978, 1979, 1980 and 1981. Wolseong nuclear power plant, Site Investigation Report, 1-4.

Dobkins, J.E. and FOLK, R.L., 1970. Shape development on Tahiti-nui. Jour. Sed. Petrol., **40:** 1156-1203.

Folk, R.L., 1968. Petrology of sedimentary rocks. Univ. of Texas, Texas Austin, Geology 370K-383L-383M, 32-83.

Huh, M., 1990. Sedimentary texture and provenance of the Cretaceous Silla Conglomerate in Daegu area, Korea. Jour. Geol. Soc. Korea, **26:** 1-11.

Jin, M.S., Kim, S.J. and Shin, S.C., 1988. K/Ar and Fission-track Datings for Volcanic Rocks in the Pohang-Kampo Area. KIER, Research Isotope Geology, KR-87-27, 51-88.

Jin, M.S., Kim, S.J. and Shin, S.C. and Lee, J.H., 1989. K/Ar and fission-track datings for granites and volcanic rocks in the southeastern part of the Korean peninsula. KIER, Research Isotope Geology, KR-88-6D, 53-84.

Jo, W.R., 1978. Geomorphic development of the Pohang coastal plain. Annals. Tohoku Geographical Associations, **30:** 152-160.

Kanehara, 1936. Geological study of northern Yeongilgun, North Kyeongsang Province, Korea, Jour. Geol. Geogr., **43:** 73-103.

Kern, J.P., Origin and history of Upper Pleistocene marine terraces, San Diego, California. Geol. Soc. Am. Bull., **88:** 1553-1566.

Kim, J.Y., 1990. Quaternary stratigraphy of the terrace gravel sequences in the Pohang area (Korea). D. Sc. thesis, Seoul National University, Seoul, Korea.

Kim, O.J., Yoon, S. and Gil, Y.J., 1968. Geologic map of Korea: Cheongha quadrangle, scale 1:50,000. Geol. Surv. Korea.

Kim, S.W., 1973. A study on the terraces along the southeastern coast (Bang-eojin-Pohang) of the Korean Peninsula. Jour. Geol. Soc. Korea, **9:** 89-121.

Krumbein, W.C., 1941a. The effects of abrasion on the size, shape, and roundness of rock particles. Jour. Geol., **49:** 482-520.

Krumbein, W.C., 1941b. Measurement and geological significance of shape and roundness of sedimentary particles. Jour. Sed. Petrol., **11:** 64-72.

Kuenen, P.H., 1942. Settling velocity and flume-behavior of non-spherical particles. Am. Geophys. Union Trans., 621-633.

Kuenen, P.H., 1956. Experimental abrasion of pebbles, 2: rolling by current. Jour. Geol., **64:** 336-368.

Lee, D.Y., 1985, Quaternary deposits in the coastal fringe of the Korean Peninsula. D.Sc. Thesis, Vrije Univ. Brussels, Belgium.

Lee, D.Y., 1987. Stratigraphical research of the Quaternary deposits in the Korean peninsula: Progress in Quaternary geology of east and southeast Asia. CCOP/TP **18:** 227-242.

Lee, D.Y., Kim, J.Y. and Yun, S.K., 1989. Quaternary Geology in the southern part of the Pohang Basin. KIER Research Report, KR-88-1B, 353-401.

Lee, D.Y., Kim, J.Y. and Yun, S.K., 1990. Quaternary Geology along the southeastern coast of the Korean peninsula (Pohang-Ulsan). KIER Research Report, KR-89-1B, 179-224.

Moss, A.J., 1962. The physical nature of common sandy and pebbly deposits. PART I. Am. Jour. Sci., Vol. **260:** 337-373.

Moss, A.J., 1963. The physical nature of common sandy and pebbly deposits. PART II. Am. Jour. Sci., Vol. **261:** 297-343.

Oh, G.H., 1977. The geomorphic history of the southeastern coast of the Korean Peninsula. Geographical Rev. of Japan, **50:** 689-699.

Rosfelder, A., 1960. Contribution á l'analyse texturale des sediments: Thesis, University of Algiers. 356 p.

Sneed, E.D. and Folk, R.L., 1958. Pebbles in the lower Colorado River, Texas; a study in particle morphogenesis. Jour. Geol., **66:** 114-160.

Tamanyu, S., 1985. Geothermy of Korea. Chishitsu News, Geol. Surv. Japan, Ser. **366:** 55-56.

Tateiwa, I., 1924. Geological atlas of Chosen: No. 2, Ennichi-Kyuryuho and Joyang Sheets. Geol. Surv. Gov. Gen. Chosen.

Um, S.H., Lee, D.W. and Park, B.S., 1964. Explanatory text of the geological map of Pohang Sheet. Geol. Surv. Korea.

Wadell, H., 1932. Volume, shape and roundness of rock particles. Jour. Geol., **41:** 310-331.

Wentworth, C.K., 1922. The shape of beach pebbles. U.S. Geol. Survey Prof., Paper, 131-C, 75-83.

Yoon, S., 1975, Geology and paleontology of the Tertiary Pohang Basin, Pohang District, Korea. Jour. Geol. Soc., Korea, **11:** 187-214.

Yoon, S., 1989. Tertiary stratigraphy of the southern Korean Peninsula. Proceeding of International Symposium on Pacific Neogene Continental and Marine Events; IGCP-246, 195-207.

Yun, H., 1986. Emended stratigraphy of the Miocene Formations in the Pohang Basin, Part I. Jour. Paleont. Soc. Korea, **2:** 54-69.

Zingg, T.H., 1935. Beitrage zur schotteranalyse. Schweizer Mineralog U. Petrog. Mitt. Bd. **15:** 39-140.

Received: November 10, 1990
Accepted: December 5, 1990