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Distribution of the Artificial Valley Fill in the Quaternary Hilly Area, Osaka, Japan

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Abstract

Hilly areas consisting of the Plio-Pleistocene in the large Quaternary basins of Japan are located adjacent to large urbanized regions and have been developed as residential suburbs by earthworks. The small valleys in these hilly areas are artificially filled in the developments. The fill areas are stable for housing residential use under normal conditions. However, many ground failures, such as sliding, liquefaction, etc., have occurred at former earthquakes. The susceptibility of artificial valley fills in the event of an earthquake is one of the potential problems in these residential suburbs. Regardless of the existence of many artificial valley fills, distributions and properties on these fills are not clear. There are several large developed areas around the urbanized Osaka Plain, southwest Japan that consist of unconsolidated sedimentary formations, the Plio-Pleistocene Osaka Group.

In this paper, artificial valley fills are detected by the comparison between old and current topographic maps. The comparison with old and current maps clarifies the thickness distribution of fills and the distribution of filled irrigation ponds which contribute to the liquefaction at earthquake. Because of the use of Quaternary layers in the neighboring ridges which are cut areas in the developing region, the fill materials are evaluated with detailed geologic maps and geologic column sections in these hills. The current slope angle is estimated with digital elevation model data of the hills. The earthquake susceptibility of fills is preliminarily evaluated with the overlapping of these properties of fills. As the result of investigation, the thickness distribution of fills and current slope angle are affected by the geological structures of the Quaternary formation. The susceptibility is evaluated higher in the adjacent areas of the flexure and uplifted areas of the Quaternary formations.

Key-words : residential suburb development, Plio-Pleistocene, susceptibility to earthquake hazard, slope stability, GRASS-GIS, topographic map

1. Introduction

The major cities in Japan, such as Tokyo, Osaka, Nagoya, Sapporo, etc., are constructed in the Holocene alluvial plains. These plains develop in the Quaternary sedimentary basins. Hilly areas are located around these alluvial plains and are the neighboring areas to the cities. Consequently, the hills have been developed as residential suburbs.

The hilly areas are leveled for housing construction. Such developments are landfills, conducted by the transportation of earth materials into the object region. The materials are cut from ridges and are filled into the valleys of the hilly areas. Such hilly areas in Japan mainly consist of the Plio-Pleistocene sedimentary formations; because these formations consist of unconsolidated mud, sand, and gravel, the development of hilly areas is easy. The development for residential suburbs has rapidly made progress since the 1960s.

The Osaka Sedimentary Basin is also composed of thick Plio-Pleistocene sediments. There are several hilly areas in this basin (Fig. 1; Itihara, 1993). These hilly areas consisting of the Plio-Pleistocene formations are developed to residential suburbs.

The 1995 Hyogoken-Nanbu Earthquake (Kobe Earthquake) caused damage to the Kobe urbanized area. In Nishinomiya City, many housing lands in the hilly area were deformed and collapsed. Many afflicted areas in the hills were located in artificial valley fills (Mitamura, 1998). It is suggested that the amplification of seismic waves and liquefaction of the soft fill materials contributed to the damage in the afflicted areas. Around the Quaternary sedimentary basin in Japan, there are many active faults which have caused many inland earthquakes (M6-8). It is important to detect the vulnerable areas to earthquake hazards.

As above, artificial valley fills susceptible to earthquake hazards are widely distributed in the Plio-Pleistocene hills around urbanized areas in Japan. The Osaka Sedimentary Basin is one such situation. The distribution of such man-made strata, however, is not clearly specified. In this paper, the distribution of the artificial valley fills by the comparison between old and

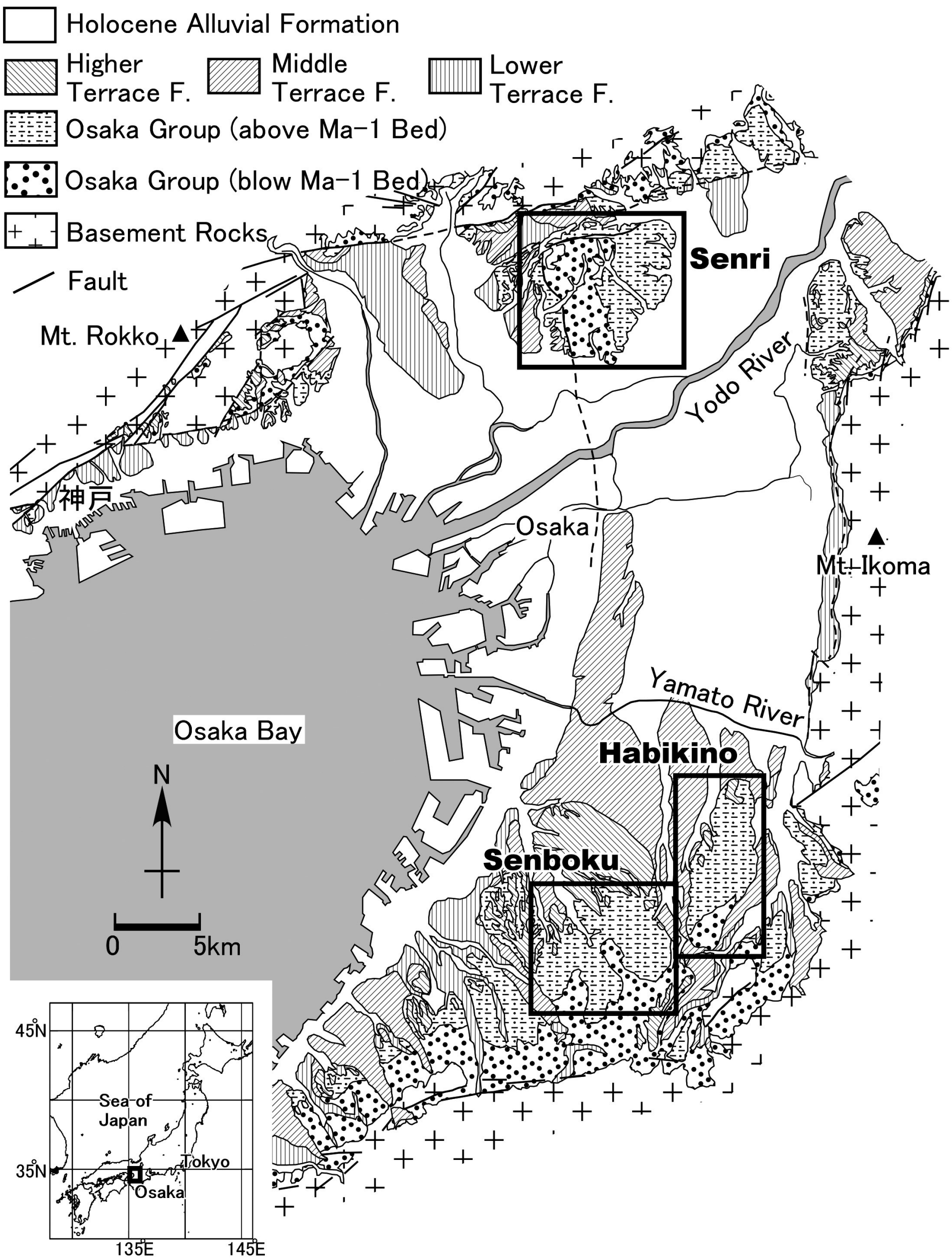

Fig. 1 Location map and Quaternary geologic map of Osaka (Edited from Itihara, 1993).

current topographic maps is reported.

2. Geological and Topographical Setting

The Plio-Pleistocene formations are widely distributed in the Osaka Sedimentary Basin; these formations are defined as the Osaka Group (Fig. 2; Itihara, 1993). The Osaka Group consists of unconsolidated clay, silt, sand and gravel. In hilly areas, the total thickness of this formation is more than 400 meters. The thickness of this group is more than 1500 meters under the Osaka Plain (Ikebe, *et al*., 1970). The lower half of the Osaka Group mainly consists of fluvial/marshy silt, sand, and gravel beds. The upper part is mainly composed of the alternation of marine clay beds and fluvial sand and gravel beds. The upper half of the Osaka Group has 12 mainly intercalated marine clay beds (Ma-1, Ma0, Ma1, Ma2, .., Ma9, Ma10). The marine clay beds are from several meters to more than 10 meters thick and are wide and horizontally distributed in the basin (Ikebe *et al*., 1970).

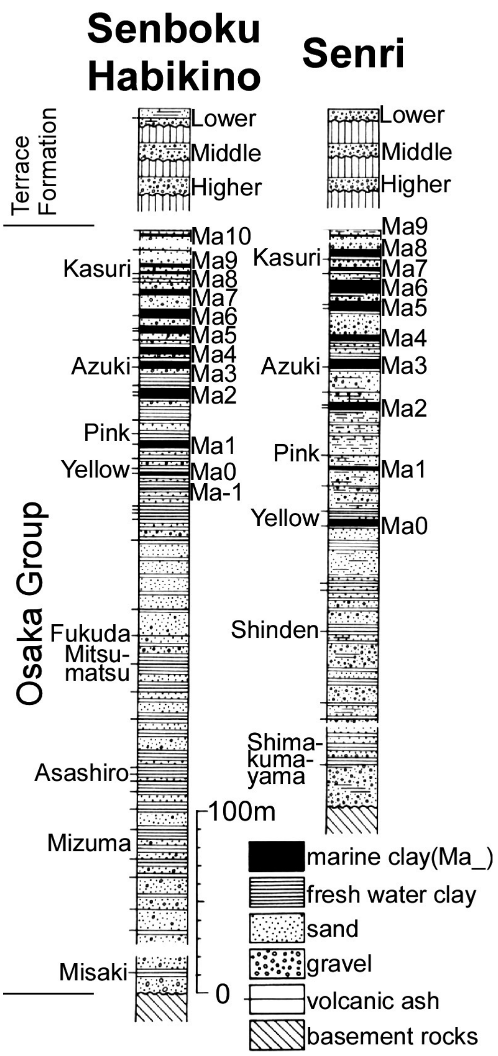

Fig. 2 Geologic column section of the Osaka Group. (adopted from Itihara, 1993).

The Osaka Plain is located around the downstream area of the Yodo River and the Yamato River. This plain is flatland less than 5 meters in altitude, consists of loose sand and soft clay/silt beds, and is about 30 meters in total thickness (Mitamura and Hashimoto, 2004). The Upper and Middle Pleistocene formed terraces around the plain and hills and are mainly divided into three terrace formations. The terrace formations are composed of sand and gravels with thickness of about 10 meters (Itihara, 1993). The northern and southern side of the plain are located several hilly areas, such as Senri, Senboku, Habikino, Hirakata, etc. The altitude of the brow of hilly areas is ranging from several tens of meters to 200 meters, and the relative relief of the hills is from approx. 50 meter. The Osaka Group is directly exposed in these hilly areas.

3. Development of Hilly Area

The hilly areas are composed of the unconsolidated Plio-Pleistocene. These sedimentary layers are easily scraped and cut with heavy earthmoving machines, such as scrapers, bulldozers, backhoes, etc. Ridges of the hill are cut with these machines; the earth materials from the scraped ridges are moved and filled to the adjacent valley. The fill materials are similar to the lithology of the Plio-Pleistocene formation in the adjacent hill ridges. Fig. 3 shows the difference between old and current topographic maps in the part of the Senri Hills. In 1961, this hilly area, which ranges from 80 to 40 meters in altitude, consisted of widely distributed bamboo, broad leaf forest, and many small irrigation ponds. In 2003, many houses and apartment buildings have been constructed on the leveled ground ranging from 50 to 60 meters, and many irrigation ponds were filled and made extinct by the development.

The Osaka Prefecture is an area that performed the earliest large-scale development as a residential suburb in hilly areas of Japan. The Senri Hills, located in the northern side of the Osaka Plain, was the first of these large scale developments and was started in 1961 by Osaka Prefecture. The main planning population and dimensions are 150,000 people and 1,160 hectares (Katayose, 1981; Osaka Prefecture, 1996). The main development was finished for the 1970 Japan World Exhibition. After the development of the main area, small scale developments have continued around the hills. The Habikino Hills, located in the southern side of the plain, has been developed since the latter half the 1960s by Osaka Prefecture, the railway companies, and the public

Fig. 3 Difference between old and current topographic maps.
Old map is the aerial photographic survey map of the Osaka Prefecture
Current map is Digital Map 25000 (Map Image), Geographical Survey of Japan (2003).

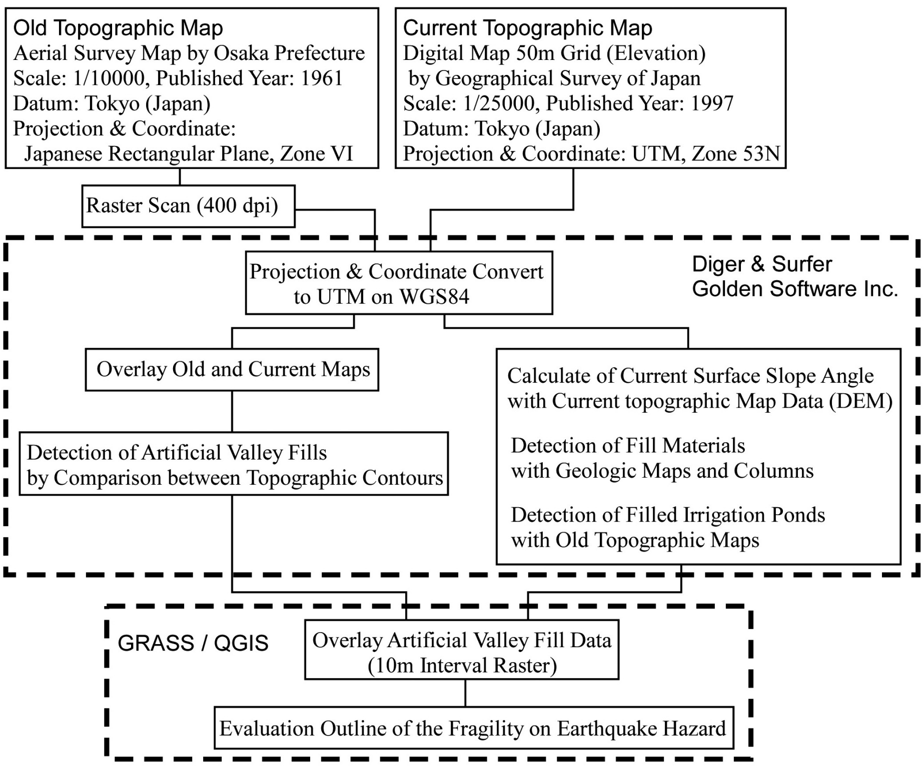

Fig. 4 Flow of Evaluation of Artificial Valley Fills.

corporation for urban development. The main planning dimension is more than 605 hectares. The Senboku Hills, located in the southern side of the plain, has been developed from 1965 to 1982 by Osaka Prefecture; the main planning dimensions are 1,847 hectares (Katayose, 1981; Osaka Prefecture, 1996).

4. Methods

1) Detection Artificial Valley Fills

There are wide distributions of artificial valley fills in the residential suburbs in the hills. These valley fills are detected by comparing old and current topographic maps (Fig. 4). The aerial photographic survey map of the Osaka Prefecture (scale: 1/10,000; Osaka Prefecture, 1961) was used as the old map. This map is the first topographic map covering the whole area of the Osaka Prefecture by aerial photographic survey, and it was made with the Gauss Kruger projection and Zone VI of Japanese Rectangular Plane on the Tokyo Datum. The current maps use Digital Map 50 m Grid (Elevation) by Geographical Survey of Japan (Geographical Survey of Japan, 1997) which is made with UTM projection (zone 53N) on the Tokyo Datum. The paper-based old map was converted to image raster data of 400 dpi with a digital image scanner. The raster data is re-coordinated with reference points (cross point of grid coordinate lines on Japanese Rectangular Plane) and converted to the UTM projection on WGS84 Datum by digitizing and coordinate conversion software (Diger 3, Golden Software Inc.). The current topographic data (DEM) are also converted to the UTM projection on WGS84 Datum, and are made to vector data of topographic contours by gridding, contouring, and surface mapping software (Surfer, Golden Software Inc.). The raster data of the old maps and the vector data of the current topography are overlaid by the Diger 3/Surfer, and the valley fill areas are detected and digitized by geologic mapping method.

Fig. 5 shows an example of the detection of valley fills. The former surface, having the relative relief from 12 to 16 meter, has been altered to smooth surface from 70 to 80 meter in altitude. The former valley has been filled up the earth materials from the former ridges. The thickness of the valley fills are about 8 meters. Several irrigation ponds in the former valleys have also been filled. It is likely that the soft sediments of the irrigation pond remain in the filled area. Liquefaction occurred at many filled inland water areas and caused damage to many buildings in the 1995 Hyogoken-Nanbu Earthquake (Mitamura, 1998).

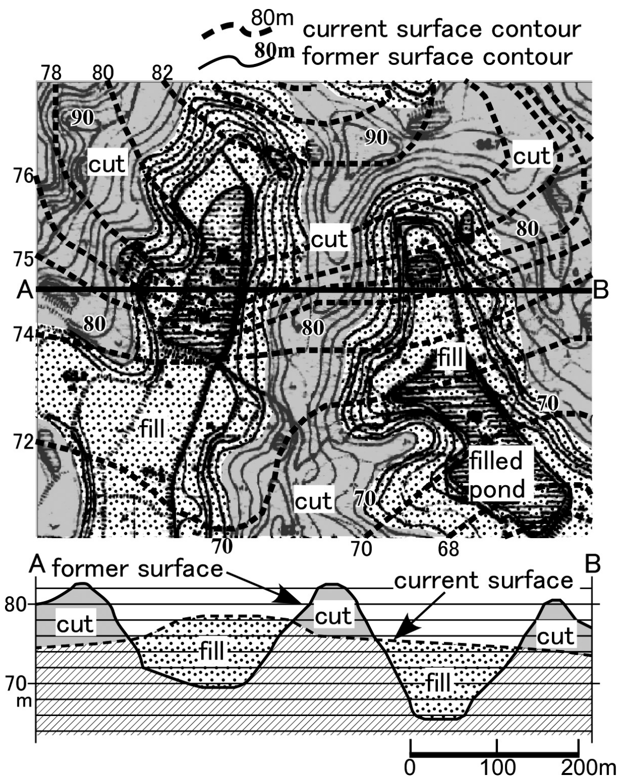

Fig. 5 Example of the detection of valley fills.

2) Current Surface Slope Angle

The current surface slope angle is calculated with DEM of the current topography by Moore *et al*. (1993). This method can estimate the slope angle on the direction of steepest decent at each point on the surface with DEM. The slope angle at each point is expressed in degrees from 0 (horizontal) to 90 (vertical).

3) Fill Materials

Fill materials are evaluated with the rate of the sand and gravel. The detailed stratigraphy of the Quaternary formations is investigated by geological surveys (Itihara *et al*., 1955, 1975; Yoshikawa, 1973). These descriptions are on the Quaternary formations with geologic column sections at points and routes in the hills. The rates of the sand and gravels with the rate of the thickness of layers to the total thickness of the each horizon between the marker beds (marine clay beds and volcanic ash layers) were evaluated. The materials were divided as sandy materials (with a rate of 50% and above) and muddy materials (less than 50%).

4) Filled Ponds

Because the precipitation during the summer season is low in the Osaka region, many irrigation ponds are constructed in hills and surrounding areas. These ponds back up the irrigation water for rice paddies in valleys with small earth dams across the valleys. In development, these ponds are reclaimed when the valleys are filled. Fig. 4 shows an example of the filled ponds. The soft pond sediments still remain in these filled pond areas (Mitamura, 2003). It is these soft pond sediments that become the liquefaction hazards to constructions. The filled irrigation ponds described in old maps were traced and digitized.

5) Evaluation on the susceptibility to earthquake

After the distributions of the factors, such as thickness of fills, current surface slope angle, fill materials, filled ponds, are rasterized to the 10 meter interval grid data, the raster data overlaid and are evaluated with GRASS GIS

(Neteler and Mitasova, 2008). The overlapping on the susceptibility of ground foundation to earthquake are described by point method with GRASS GIS.

5. Results

Figs. 6, 7, 8 show the results of the detection and evaluation of valley fills, current surface slope angle, fill materials, and filled ponds in the Senri, Senboku, and Habikino Hills. This section describes the result of the distribution of the factors on the susceptibility to earthquake.

1) Thickness of Fills

Fig. 6 shows the result of the detection of thickness of valley fills in the Senri, Senboku, and Habikino Hills.

In the Senri Hills, the area of the valley fills is 1236 hectares, and the area rate to development region is 47.1%. The valley fill area that is less than 10 meters thick is 88% of the total fill area. The portions of fills more than 15 meters thick are located in the south of Kayano and northeast of Yamada. In particular, the eastern region is thicker than the middle to southwestern regions.

In the Senboku Hills, the area of the valley fills is 1415 hectares, and the area rate to development region is 46.7%. In the Senboku Hills, thick valley fills more than 15 meters thick generally distribute along the bottom of the former main valley in the eastern part of the hills. Moreover, the thick valley fills are widely distributed in the north side of the Komyo-ike.

In the Habikino Hills, the area of the valley fills is 1184 hectares, and the area rate to development region is 58.1%. Generally, the fills less than 10 meters thick are widely distributed in these hills. The thick valley fills are found in the axial region of the hills trending north to south.

2) Current Surface Slope Angle

Fig. 7 shows the evaluation result of the current surface slope angle in the Senri, Senboku, Habikino Hills. The current slope angle in any development areas in the three hill regions is almost gentle. The slope angle of more than 90% fill area is less than 6 degrees. This result suggests that the former hilly areas altered to become level ground for the housing sites.

The level ground is widely distributed in the central area of the Senri Hills. Especially, the areas of the 1970 Japan World Exhibition are well-flattened areas. The sloping terrains distribute along the northern and western margins of the Senri Hills.

The main development area of the northern and eastern parts in the Senboku Hills is also well-flattened. Because the hilly area still remains in the southern part of the hill, the slope angle of more than 10 degrees distributes in this part. There are also sloping grounds along the main valleys in the Senboku Hills.

In the Habikino Hills, the main developed areas distribute in the central and northern part. These areas are also well planarized. The sloping grounds are distributed along the eastern margin of the hills.

3) Fill Materials

Fig. 9 shows the thickness of the sand and gravels in the three hills. Coarser sediments are spread in the Senri Hills, as compared to the other hills. In the Senboku and Habikino Hills, mud fill materials, which are less than 50% of the amount of the sand and gravels, are evaluated at the horizon between the Ma1 and Ma4 beds, indicating the rate from 24.2 to 27.6%. In the Senri Hills, mud fill materials are evaluated at the horizon between the Ma2 and Ma6 beds, indicating the rate of 46.0%. In the Senri Hills, the area of sandy fill materials covers 91.4% of the whole filled valley.

The distribution of the fill materials are affected by the geologic structure (Fig. 8). Most areas of the Senri Hills consist of sandy materials. The valley fills consisting of muddy materials distribute in the eastern part and the western margin of the hills. The valley fills of muddy materials mainly distribute in the southern part of the Senboku Hills and in the central part and eastern margin of the Habikino Hills.

4) Filled Ponds

There are many filled ponds detected in the three hills. The physical volume of the filled ponds in the Senri, Senboku, and Habikino Hills approach 760, 390, and 334 susceptible areas (Fig. 8). There were many small ponds in the Senri Hills.

6. Discussion

1) Distribution of Fills

The thickness distribution of artificial valley fills depends on the former surface properties and the configuration of the improved land. The area rate of the valley fills to the development region in the Senri Hills and the Senboku Hills are slightly less than 50%. This is because the volumes of the cut and the fill must maintain equilibrium in the development plan. However, the area rate of the valley fills in the Habikino Hills is relatively higher than the others. These hills were developed by several developers. Several developed areas in Habikino

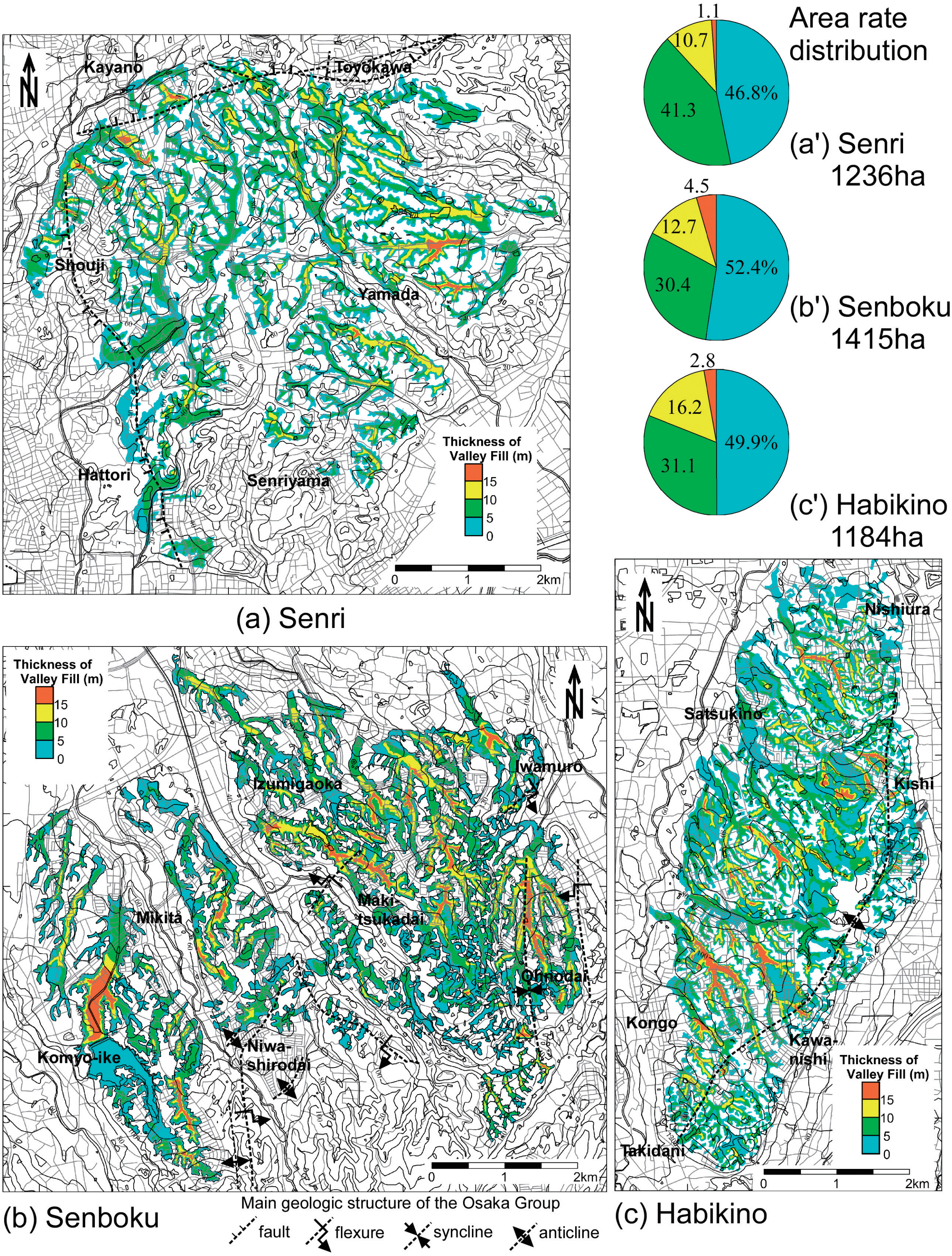

Fig. 6 Thickness Distribution of the artificial valley fills and main geologic structures of the Osaka Group in Senri, Senboku, and Habikino Hills Geologic structures of Osaka Group are adopted from Itihara (1993).

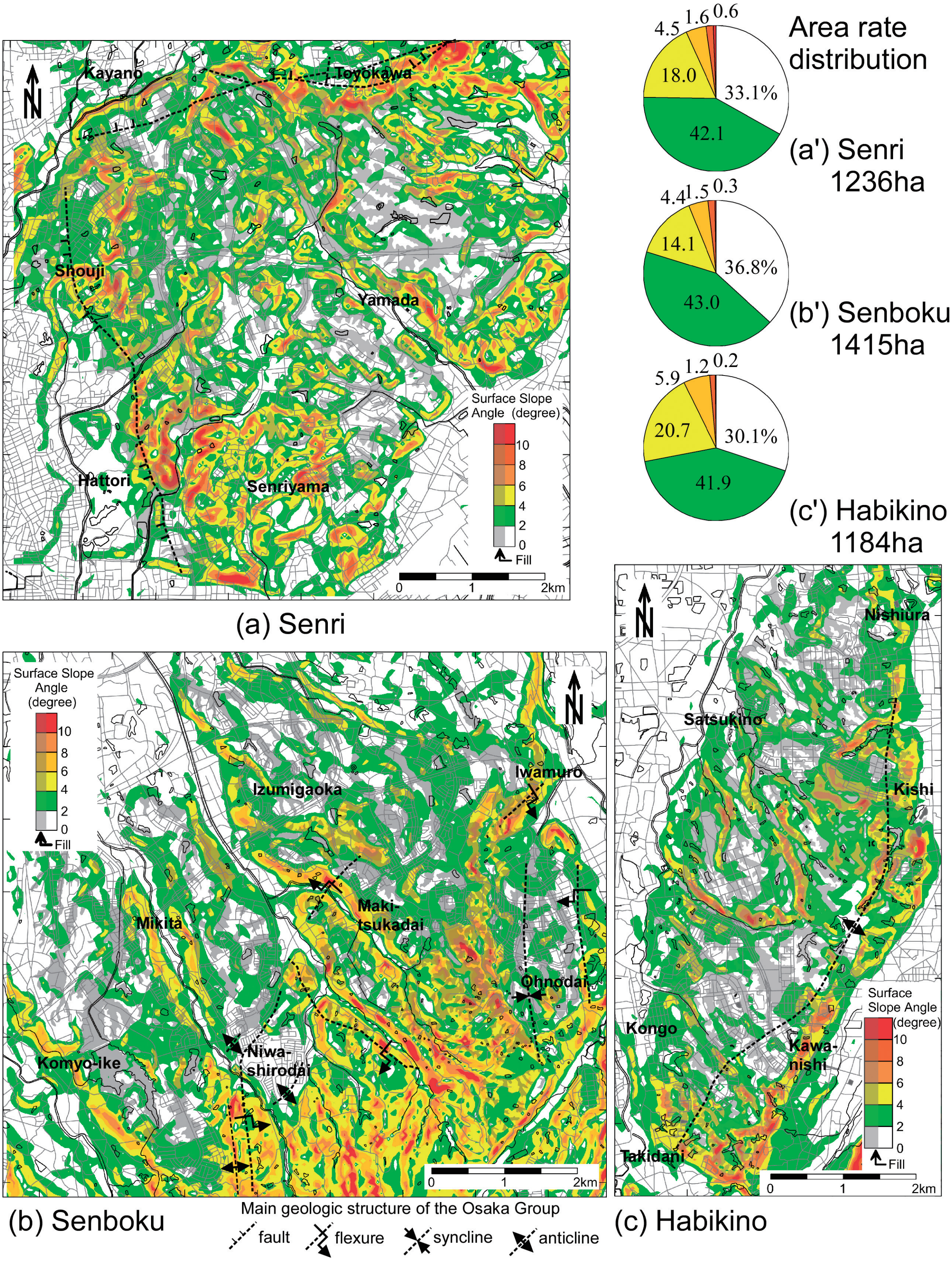

Fig. 7 Slope Angle Distribution of Current Surface in the Senri, Senboku, Habikino Hills.

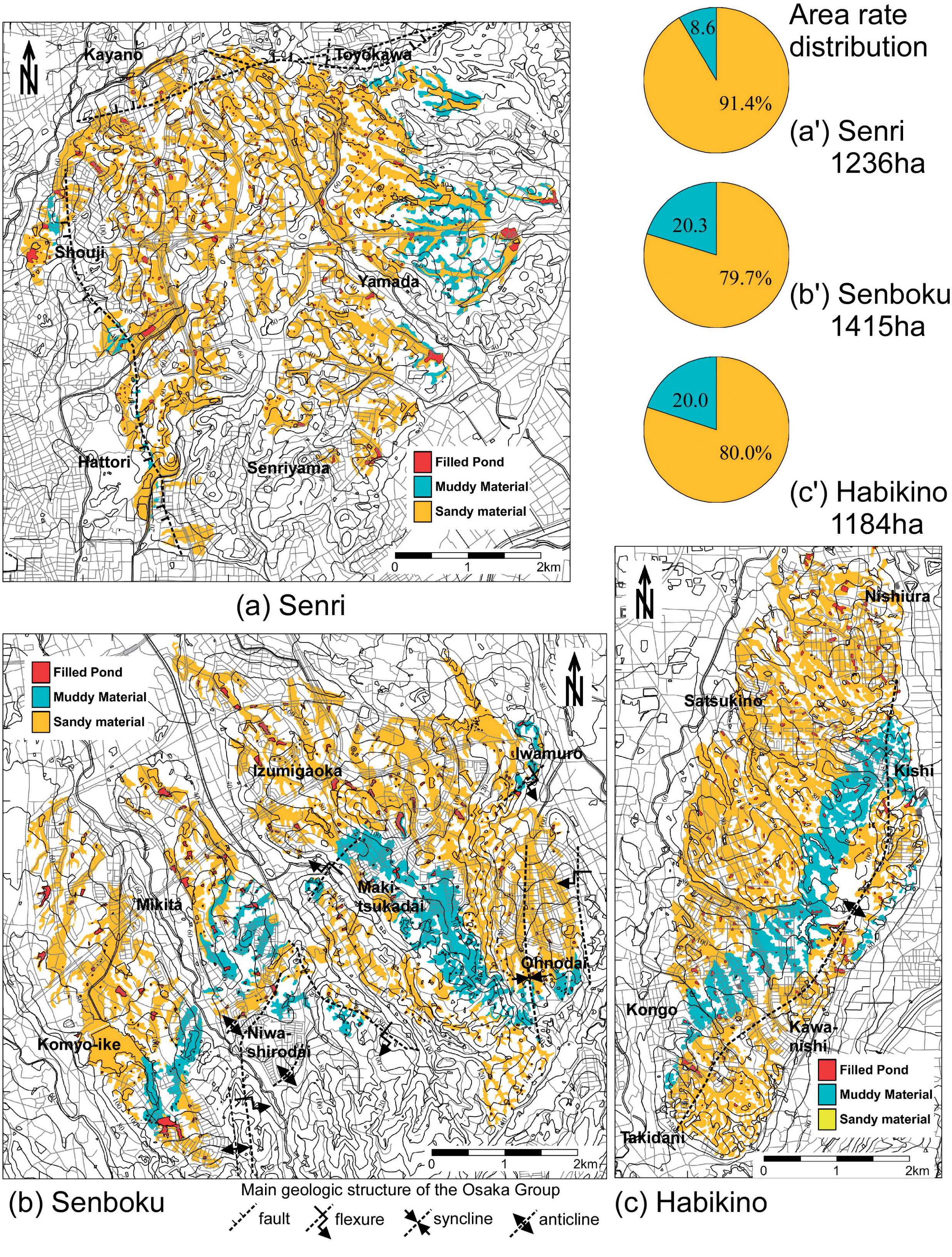

Fig. 8 Distribution of Fill Materials and Filled up Irrigation Ponds in the Senri, Senboku, Habikino Hills.

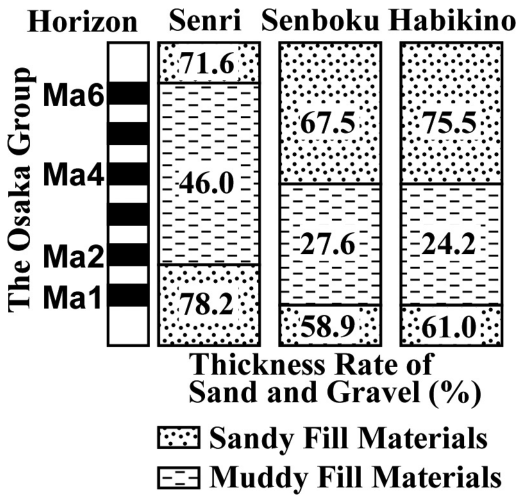

Fig. 9 Thickness Rate of Sand and Gravels in the Senri, Senboku, Habikino Hills.

Table 1 List of Scores of Each Factor on the Susceptibility to Earthquake.

Item	Category	Susceptibility Score	
		Sandy Fill Materials	Muddy Fill Materials
Thickness of Fill	15 m and above	0.25	1.00
	From 10 m to 15 m	0.50	0.75
	From 5 m to 10 m	0.75	0.50
	Less than 5m	1.00	0.25
Filled up Pond	Distribution	0.50	
	Non-distribution	0.00	
Current Slope Angle	10 degree and above	1.00	
	From 8 to 10 degree	0.80	
	From 6 to 8 degree	0.60	
	From 4 to 6 degree	0.40	
	From 2 to 4 degree	0.20	
	Less than 2 degree	0.00	

Hills are divided into main valleys. In the margin of each developed area, cut earth materials are dispersed to the slope of these main valleys, and thus formed the stepwise housing sites. The fills of less than 10 meters thick along the main valley correspond to these stepwise housing sites. There are also similar distributions of fills from Shoji to Hattori in the western part of the Senri Hills.

In the north side of the Komyo-ike in the Senboku Hills, thick valley fills are widely distributed along the main valley. This site has been the main disposal site of earth materials from the surrounding cutting areas. In the north side of the Yamada of the Senri Hills, also lies distributed thick valley fills. This area was developed for the 1970 Japan World Exhibition and has been widely altered to a flattened area.

Generally, the areas of thick valley fills are former valleys having large relative relief to the surrounding ridges. These thick valley fills are not evenly distributed in the three hills. As mentioned above, the distributions of these thick valley fills are in the northern part of the Senri Hills, eastern part of the Senboku Hills, and axial region of the Habikino Hills. Fig. 6 also shows the main geologic structure of the Osaka Group. The Osaka Group in Senri Hills is tilted to the south and east with two fault systems (Itihara, 1993). Because of these geologic structures, the northern part has relatively high altitude, and has large relative relief. The distribution of the current surface slope angle along the northern margin is also steeper than the central area. In the eastern part (around Makitsukadai) of the Senboku Hills, the Osaka Group formed an uplifted zone with several geologic structures (Itihara, 1993). The steeper slopes are distributed along these structures. There is an anticline axis along the eastern margin of the Habikino Hills. The Osaka Group formed an asymmetry anticline along this axis (Itihara, 1993). The drainage divide in the Habikino Hills is nearly formed along this axis. The eastern margin of this hill along the eastern wing on this axis formed steeper slopes. The concentrated areas of thick valley fills in these three hills are located around the structural uplifted zone of the Osaka Group. It suggests that the distribution of valley fills is also affected by the tectonic relief in the Quaternary.

2) Evaluation on Susceptibility to Earthquake

The former earthquake disasters exposed the susceptibility of artificial valley fills to earthquake (Mitamura, 1998, 2003; Kamai & Shuzui, 2002).

Kami & Shuzui (2002) investigated and compared the behavior of fill deformation due to former earthquake disasters. At the 1978 Miyagi-ken-oki Earthquake, thick fills were deformed at a high percentage. On the other hand, thinner fills were deformed at a high rate at the 1995 Hyogoken-Nanbu Earthquake. There is a difference in the fill materials in these examples. The fill materials mainly consist of the muddy sediments in the Sendai Area, Miyagi. While, in Kobe to Nishinomiya area, Hyogo, fill materials are mainly composed of sandy materials. Sandy materials are weak due to small effective stress at shallow depth. On the other hand, the muddy materials having cohesion is more stable at shallow depth than sandy materials. In the case of the shallow groundwater table, sandy materials at shallow depth are easily liquefied by the strong earthquake motion. It is thought that the difference

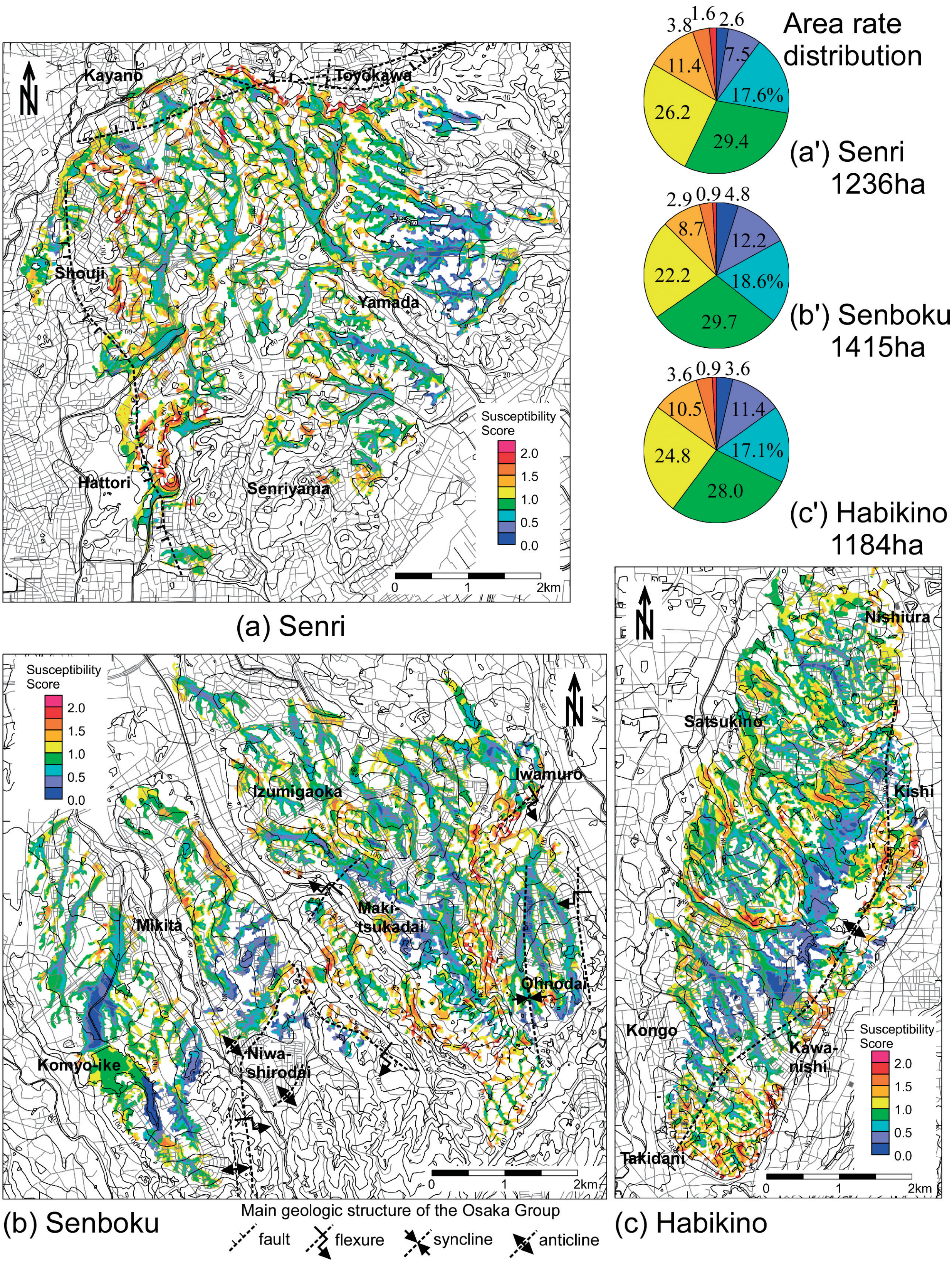

Fig. 10 Susceptibility Score Distribution of valley fills in the Senri, Senboku, Habikino Hills.

of the properties of fill materials is important on the behavior of fill deformation.

As mentioned above, there are many irrigation ponds in the hilly area surrounding Osaka. Many of these ponds were filled up for the residential suburb developments. Soft sediments often remain at these reclaimed pond areas (Mitamura, 2003). These soft sediments, including groundwater, contribute to the liquefaction by main shock. The current slope angle also has an influence on the stability of fill slopes.

The detected and evaluated items mentioned above, such as fill thickness, materials, distribution of reclaimed ponds, and the current slope angle, are important factors on the susceptibility of the housing grounds to earthquake. As the preliminary evaluation, we estimated the distributions of these factors at each 10 meter interval grid by point method with evaluation score shown in Table 1. The thickness and slope angle have a maximum score of 1.0, giving added weight to susceptibility. The distribution of filled up pond is 0.5 as the susceptibility score.

Fig. 10 shows the distribution the susceptibility score of valley fills in the three hilly regions. The fractions of the scores in three hilly areas are almost same (Fig. 10.a, b, c). The susceptibility of mud fill materials is lower than sandy materials when the thickness of fills is less than 10 meters. The higher scores of more than 1.5 disproportionately distributes in each hill. These distributions are located along the main valley of the margins of the development area and along the margins of the uplifted area of the Plio-Pleistocene. For example, the northern and western margins in the Senri Hills have higher scores. The surrounding areas of Makitsukadai, Senboku Hills and the eastern margin of the Habikino Hills also have higher scores. The distribution of thin fills forming relatively steep slopes at these portions has an influence on the higher score. It suggests that the distribution of the susceptibility of the fill ground to earthquake is also affected by the tectonic relief in the Quaternary.

7. Conclusion

The result of the detection on the artificial valley fills in three Plio-Pleistocene hills, such as Senri, Senboku, and Habikino Hills, leads to the following conclusions.

(1) Almost half of the area in the development regions for the residential suburb in these hills is artificial valley fills. The fills less than 10 meter thick account for about 80% of the area.

(2) The distribution of the valley fills depend on the configuration of the improved land. In the Habikino and Senri Hills, the fills of less than 10 meter thick along the main valley correspond to these stepwise housing sites. The thickness of the fills in the flattened upper part of the hill depends on the relative relief of the hill.

(3) The thick valley fills are distributed in the uplifted zone of the Osaka Group with several geologic structures. The thickness of valley fills is also controlled by the tectonic relief in the Quaternary. The tectonic relief also affects the susceptibility of the fill ground to earthquake.

This study mainly detects the distribution of the artificial valley fills in three hill regions with comparison of old and current topographic maps and evaluation of susceptibility scores of these fills to earthquake. In order to reveal more about the susceptibility on these fills, we need to evaluate the physical and mechanical properties of these fills, such as grain size distribution, density, shear wave velocity, compressive strength, etc.

References

Geographical Survey of Japan (1997) Digital Map 50m Grid (Elevation) NIPPON-II. Geographical Survey of Japan, Ibaragi, CD-ROM.

Ikebe N., Iwatsu J., Takenaka J. (1970) Quaternary Geology of Osaka with Special Reference to Land Subsidence. Jour. Geosci., Osaka City University, Vol.13, 39-98.

Itihara, M. (1993) The Osaka Group. Sougen-sha, Osaka, 340p. (in Japanese)

Itihara, M., Hujita, K., Morishita, A., Nakaseko, K. (1955) Stratigraphy of the Osaka Group in the Senriyama Hills : Study on the Osaka Group (Part I). Jour. Geol. Soc. Japan, Vol.61, 433-441.

Itihara, M., Yoshikawa, S., Inoue, K., Hayashi, T., Tateishi, M., Nakajima, K., (1975) Stratigraphy of the Plio-Pleistocene Osaka Group in Sennan-Senpoku Area, South of Osaka, Japan - A standard stratigraphy of the Osaka Group -. Jour. geosci., Osaka City Univ., Vol. 19, 1-29.

Kamai, T. and Shuzui, H. (2002) Slope Disaster Prevention City - Prediction and Countermeasure for Slope Disaster in City Area-. Rikoh Tosho, Tokyo, 200p. (in Japanese)

Katayose, T. (1981) Experimental City -How has the Senri New Town been constructed ?-. Shakai Sisou-sha, Tokyo, 261p. (in Japanese)

Mitamura, M. (1998) Artificial alteration of landform in inland of Hanshin area. Report on the Hanshin-Awaji Earthquake Disaster, General Issues Vol. 2, The Editorial Committee of Report on the Hanshin-Awaji Earthquake Disaster, Maruzen, Tokyo, 354-360. (in Japanese with English abstract)

Mitamura, M. (2003) Artificial valley fill and reclaimed pond area at the 1995 Hanshin-Awaji Earthquake Disaster. Urban Kubota, Kubota Co. Ltd., Osaka, No.40, 26-37. (in Japanese)

Mitamura M. and Hashimoto M. (2004) Spatial Distribution with the Drilling Database on the Basal Gravel Bed of the Namba Formation in the Osaka Plain, Southwest Japan. The Quaternary Research, Vol.43, 253-264. (in Japanese with English abstract)

Moore, I. D., A. Lewis, and J. C. Gallant, (1993), Terrain properties: Estimation Methods and Scale Effects, Modeling *Change in Environmental Systems*, A.J. Jakeman *et al*. eds., John Wiley and Sons, New York, Ch. 8, 189-214.

Neteler, M. and Mitasova, H. (2008) Open Source GIS: A GRASS GIS Approach. Third Edition. The International Series in Engineering and Computer Science: Volume 773., Springer, New York, 406 p.

Osaka Prefecture (1961) The aerial photographic survey map of the Osaka Prefecture. Planning Division, Governor's Office, Osaka Prefecture, 52 sheets. (in Japanese)

Osaka Prefecture (1996) Master Plan of the housing in the Osaka Prefecture. Hosing Policy Division, Osaka Prefecture, 229p. (in Japanese)

Yoshikawa, S. (1973) The Osaka Group in the southeast of Osaka. Jour. Geol. Soc. Japan, Vol. 79, 33-45. (in Japanese with English abstract)

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