GEOMORPHOLOGICAL FEATURES AND SUBSURFACE GEOLOGY OF THE LOWER MEKONG PLAIN AROUND PHNOM PENH CITY, CAMBODIA (SOUTHEAST ASIA)

Sumiko Kubo
Department of Geography, Waseda University, Tokyo, 1698050 Japan
sumik@waseda.jp

ABSTRACT

The geomorphological features of the Lower Mekong Plain and their relationships with floods, as well as the subsurface geology and the major depositional processes in the area, are discussed. From the interpretation of aerial photos and field reconnaissance, the Lower Mekong Plain in Cambodia is characterized as a floodplain with natural levees and back marshes. These geomorphological features influence the extent of the extensive inundation that occurs during every rainy (wet) season. An extreme flood in 2000 confirmed the close relationship between micro-landforms and the flooding. A preliminary study of bore-hole logs in the area of Phnom Penh was also carried out. Base rocks are shallower in the western part, whereas thick (>130 m) Quaternary deposits occur in the eastern part, suggesting the presence of a structural basin.

Keywords: Mekong, micro-landforms, flood, satellite image, subsurface geology

1. INTRODUCTION

The Mekong is the largest river in Southeast Asia. Although its length, about 4800 km (Mekong River Commission, 2005), is roughly the same as that of the Paraná River, the drainage area of the Mekong is 795×10^3 km^3, far smaller than that of the Paraná (2800×10^3 km^3). As is true of the Amazon and the Paraná, the Mekong is an international river. Its source is located in the Eastern Tibetan Plateau in China (c. 5000 m a.s.l). After flowing through southwestern China, it comes into the areas bordering Myanmar (Burma), Lao PDR (Laos) and Thailand. The lower reaches belong to Cambodia and Vietnam (figure 1).

A savanna climate similar to that of the Araguaia River prevails in the Lower Mekong Basin. The mean monthly temperature in Phnom Penh (Cambodia) ranges between 26.0°C (December) and 31.0°C (April). May to October is classified as the rainy (wet) season, and the rest of the year from November to April is called the dry season. The annual rainfall in Phnom Penh is 1320 mm (Mekong River Commission, 2005); more than 80% falls in the rainy season. The mean annual discharge of the Mekong is 475 km^3, and the mean monthly flow at Kratie (in eastern Cambodia) ranges from 2200 m^3/s (Apr) to 36 700 m^3/s (Sep) (Mekong River Commission, 2005).

The capital of Cambodia, Phnom Penh, is located on the Cambodian Plain at the junction of the Mekong and Tonle Sap rivers. The Tonle Sap River connects the Mekong with the massive Tonle Sap Lake. During the rainy season “reverse flow” from the Mekong feeds the Tonle Sap Lake, increasing its area by up to 3 times the dry-season area (Hori, 2000). Such a unique hydrological regime characterizes the Cambodian Plain. Also at Phnom Penh the Mekong diverges into the Bassac River and the mainstream, forming the uppermost part of the Mekong Delta.

As the political circumstances in the Mekong Basin improved, the number of geomorphological surveys has recently been increasing (e.g. Kubo, 2004, 2006; Gupta and Liew, 2006; Oketani et al., 2007). I intend in this paper to clarify the unique geomorphological aspects of the Lower Mekong Plain. The main topics are (1) the geomorphological features of the plain, as detected by micro-landform interpretation, (2) the relationships between these geomorphological features and floods, and (3) the subsurface geology of the plain, especially with regard to alluvial deposits of the Mekong.

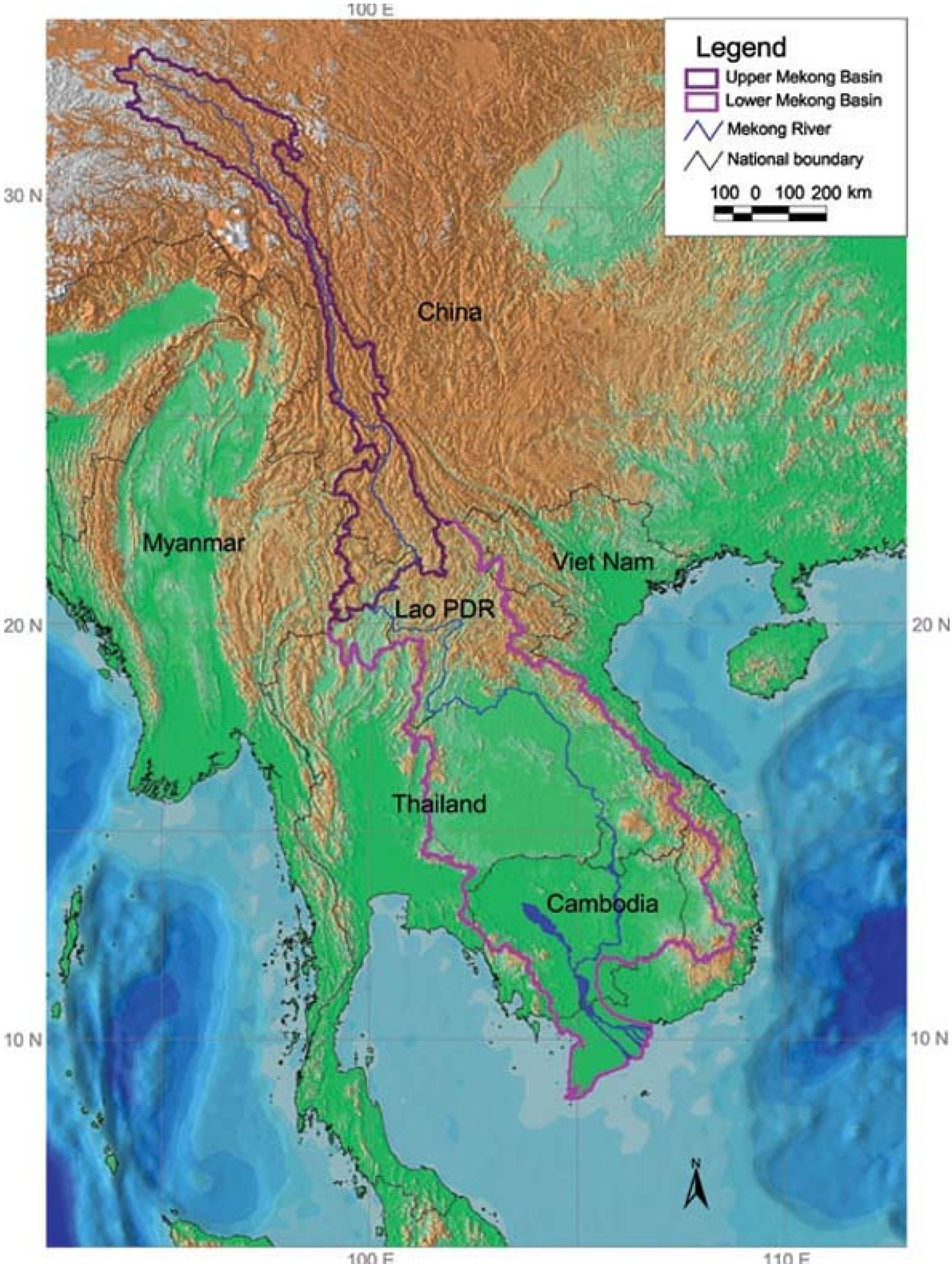

Figure 1 - The Mekong River Basin (MRC, 2003)

2. MATERIALS AND METHODS

A geomorphological map of the Lower Mekong Plain was produced by using:

- topographic maps of Cambodia (1:50 000), published between the 1960s and 70s,
- topographic maps of Cambodia (1:100 000), published between 1999 and 2003, and
- aerial photos taken in 1992 (c. 1:25 000) by FINNMAP.

Micro-landforms were interpreted from stereo pairs of aerial photos. These micro-landforms were then recorded on 1:100 000 topographic maps.

JERS-1, Landsat-7, and SPOT satellite images were used to examine flooded areas in the monsoon (wet) seasons of 1992 to 2002. JERS-1 (Fuyo-1) was a Japanese Earth observation satellite. Data available from this satellite covered the period from November 1992 to October 1998. The Synthetic Aperture Radar (SAR) sensor aboard this satellite had an 18-m resolution and is not influenced by weather conditions nor by whether it is day or night. Water bodies appear as dark areas in SAR images. Landsat-7 Enhanced Thematic Mapper Plus (ETM+) images from 1999 onward are available. There are 8 bands in the visible and infrared spectrum. The bands used in this study have a resolution of 30 m. Because ETM+ shows cloud cover, images with low cloud cover were chosen. The JERS-1 images analyzed are from 11 September 1992, 16 September 1995, 3 October 1997, and 20 September 1998; Landsat-7 images are from 24 September 1999, 26 September 2000, 15 October 2001, and 2 October 2002. A SPOT image from 27 September 2000 was taken after an extreme flood occurred.

Bore-hole logs of buildings and bridges in and around Phnom Penh city were used to clarify the subsurface geology, especially with regard to alluvial deposits of the Mekong. The bore-hole logs were provided by Cambodian government ministries (MPWT[1] and MRD[2]), international organizations (MRC[3] and JICA[4]), and the Japanese government (MoFA[5]).

I examined 33 bore-hole logs from within Phnom Penh city (including logs from the Chroy Changvar Bridge, Phnom Penh Port, Japanese Embassy, and some other buildings), 15 logs from around Phnom Penh city (including those from National Roads No. 6A and No. 7 [the Mekong Bridge] and irrigation canals [*colmatage* canals] in Kandal Province), and an additional 6 logs of deep wells for ground-water research (Kubo, 2003b). In this paper 8 representative logs are mentioned.

Field reconnaissance was done during both the wet and dry seasons. Supplementary observations of outcrops and hand drilling were used.

3. RESULTS

3.1 GEOMORPHOLOGICAL FEATURES OF THE PLAIN

Figure 2 is a geomorphological map of the plain produced by the author, showing local variations in the geomorphological features of the plain. The Mekong, Tonle Sap, and Bassac rivers form a “K” shape at Phnom Penh. This area is called the Chaktomuk Junction. Kubo (2004) summarized the geomorphological features in the area as follows:

1) Uplands and alluvial fans are present in the western part. A gentle alluvial fan is also present along the Praek Tnaot River. The city of Phnom Penh is located on the eastern margin of this gentle fan. To the north and south of this fan, terrace-like uplands border the floodplain. Residual hills (monadnocks) and surrounding pediments are sometimes seen.

2) The Mekong floodplain extends from the Kampong Cham district to the Vietnamese border. Near Kampong Cham, some 70 km upstream from Phnom Penh, higher uplands and basalt plateaus narrow the floodplain. Downstream from this narrower part, from Kampong Cham to Phnom Penh, the

[1] Ministry of Public Works and Transportation; [2] Ministry of Rural Development; [3] Mekong River Commission; [4]Japan International Cooperation Agency;[5]Ministry of Foreign Affairs

Mekong's channel changes from a braided pattern to a meandering pattern, and the channel frequently shifts. Evidence of channel shifting and consequent bank erosion can be seen in several parts; this was confirmed by comparing the present channel location with that shown on old topographic maps. Abandoned channels of the Mekong can be seen as the Praek Kang Chak and Preak Mukh Kampul along the right bank; they show traces of the former Mekong channel.

The floodplain near the Chaktomuk Junction is characterized by natural levees and back marshes. Natural levees are also present along the Mekong near Phnom Penh and the Tonle Touch, a small distributary, but the natural levees along the Mekong are comparatively small in scale, being less than 1000 m wide. Major roads and villages are located on these narrow natural levees.

3) The Tonle Sap River floodplain is low and swampy. This river flows along the western margin of the lowland. The direction of flow reverses between the dry and rainy seasons. The reverse flow from the Mekong to Lake Tonle Sap during the rainy season increases the area of the lake to 3 times its dry-season area. Although the channel is stable, natural levees are poorly developed, and swampy back marshes occur between the Tonle Sap River and the Mekong.

4) The Bassac River floodplain is characterized by dense irrigation canals. The Bassac River diverges from the Mekong at Phnom Penh. Extensive natural levee-like features radiate from the main channel. These slightly elevated lands have developed along the number of "*colmatage*" irrigation canals connected to the Bassac. During the rainy season these canals carry water and deposits into the back marshes.

5) Slightly higher alluvial surfaces surround the floodplain. These surfaces are irregular and rough. The border between these surfaces and the floodplain is indistinct and is generally defined by the transition from paddy fields to swampy areas. Major roads and villages are located on this surface.

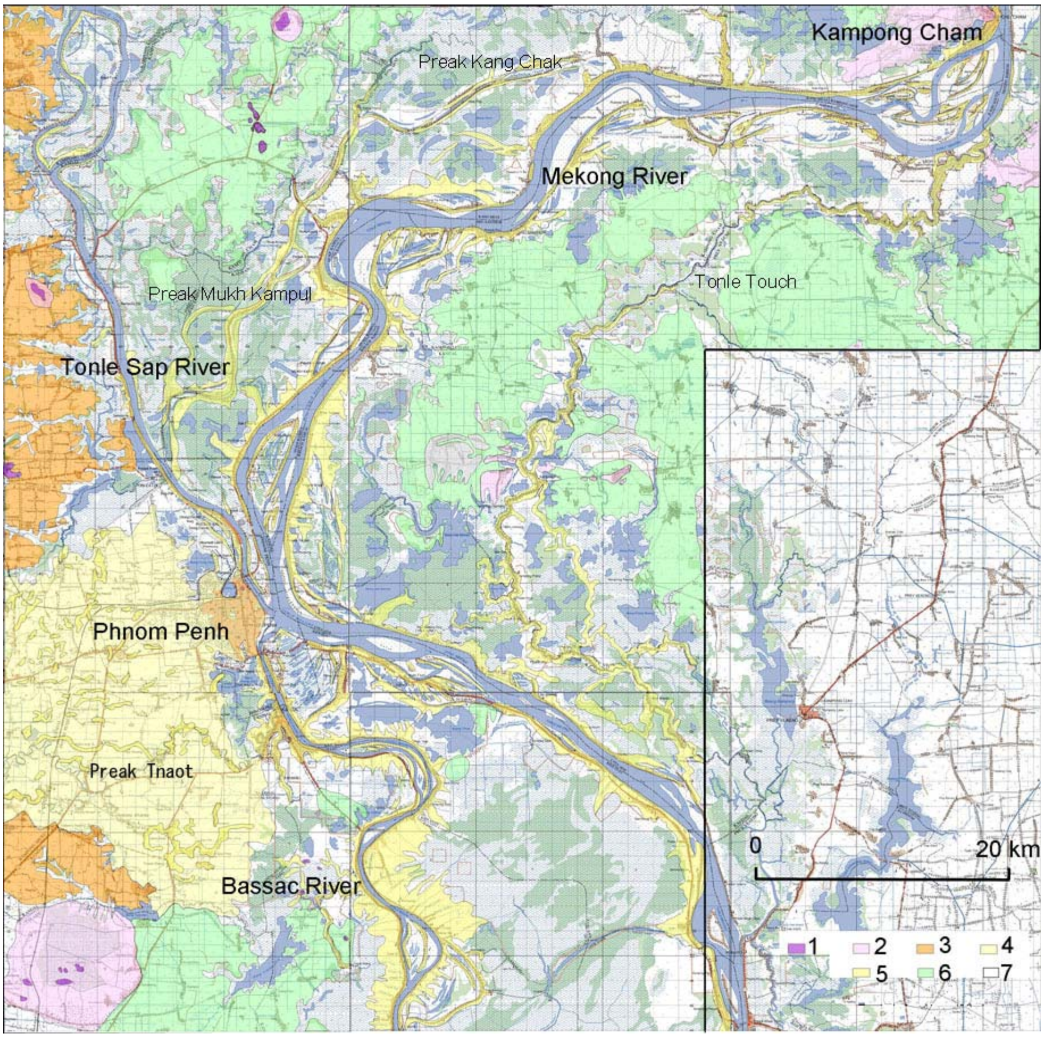

Figure 2 - Geomorphological map.1: hill, 2: pediment, 3: upland, 4: alluvial fan, 5: natural levee, 6: higher alluvial surface, 7: back marsh (Base map: 1:100000 Topographic Map of Cambodia)

3.2 SATELLITE IMAGES OF FLOODS (figures 3–5)

To detect flooded areas during the rainy season, 9 images taken by 3 satellites (JERS-1, Landsat-7, and SPOT) were analyzed. JERS-1 images from 1992 to 1998 and Landsat-7 images from 1999 to 2002 show flooded areas in the late rainy season. Images from 1992 and 1998 show less water coverage, whereas images of 2000 and 2002 show larger areas of water. Mekong River Commission (2005) describes these years as drought years and flood years, respectively.

During the rainy (wet) season, an extensive area along the Chaktomuk Junction becomes inundated. However, narrow, water-free areas occur on both sides of the Mekong River and along tributaries such as Tonle Touch, Preak Kang Chak, and Preak Mukh Kampul. The light-colored area on the right banks of the Mekong and Bassac rivers is the city of Phnom Penh (figure 3). The significant linear border of inundation perpendicular to the Tonle Sap River located northwest of Phnom Penh (figure 4) indicates the Kop Srav Embankment. Dry areas extend from the remaining areas more distant from the rivers.

An extreme flood in the lower Mekong Basin occurred in the year 2000. The water level of the Mekong increased rapidly in July, 2 months earlier than in normal years, and Lake Tonle Sap was full by the end of July. Consequently, flooding was sustained from early September to October. The highest water level (11.2 m) in 30 years was recorded at Phnom Penh on September 20. Therefore, the Landsat-7 image from September 26 and the SPOT image from September 27 show the flood nearly at its highest point. Those images show heavy inundation, especially on the left bank of the Mekong.

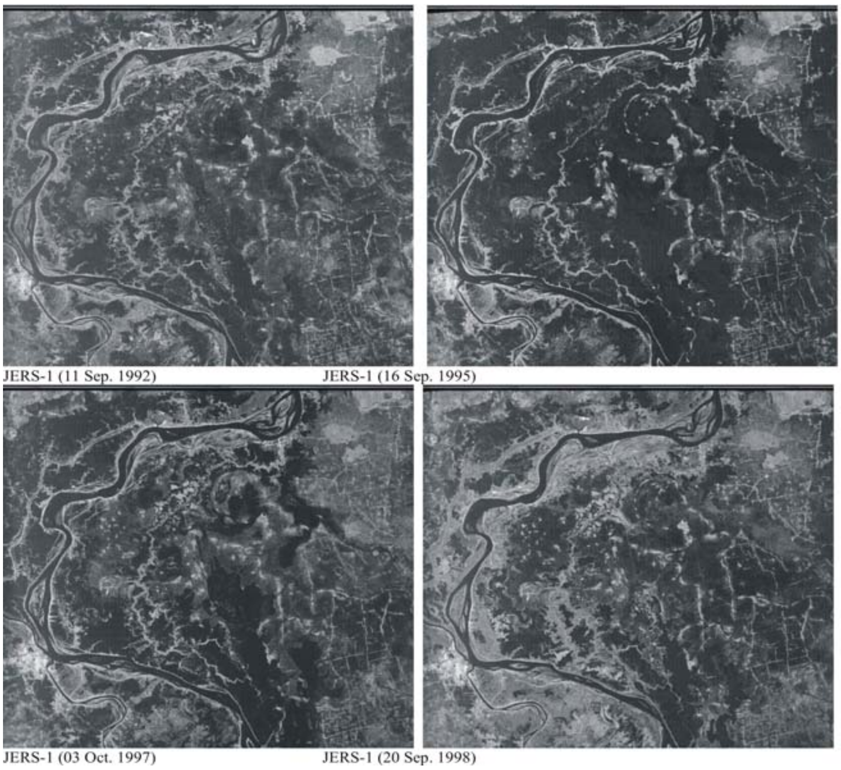

Figure 3 - JERS-1 SAR images (RESTEC; Remote Sensing Technology Center of Japan).

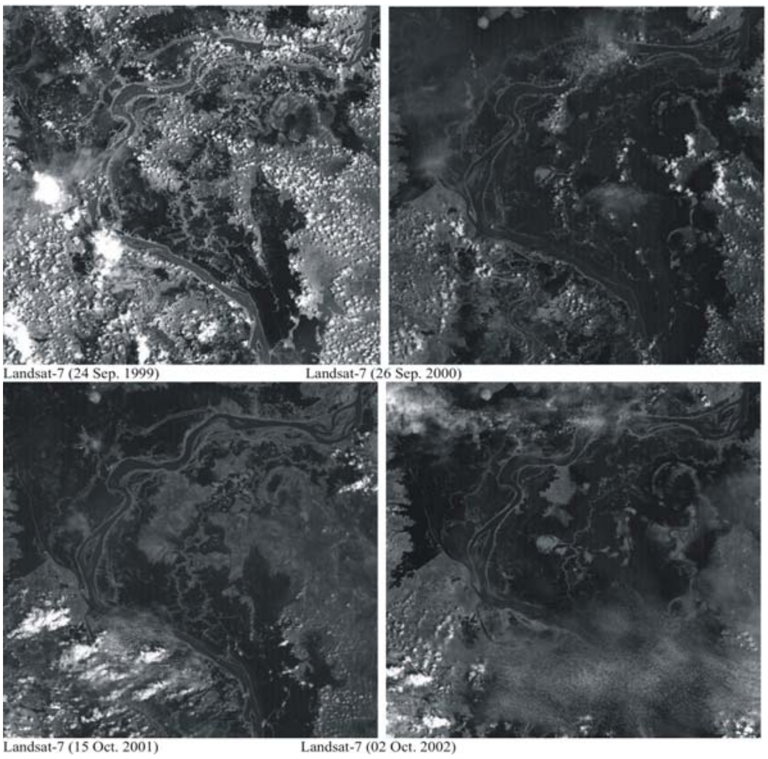

Figure 4 -Landsat-7 near-infrared images (USGS; United States Geological Survey).

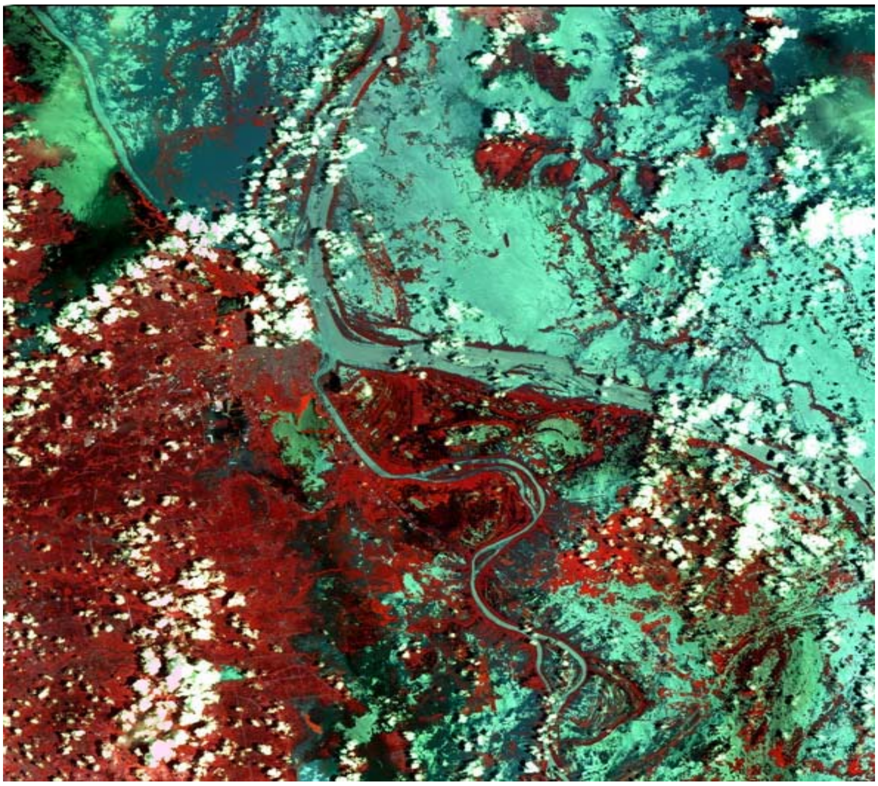

Figure 5 - SPOT image (27/09/2000) (CNRS; French National Center for Scientific Research).

3.3 DESCRIPTION OF BORE-HOLE LOGS

Representative columnar sections of bore-hole logs are shown in Figure 6a. Log No. 1 shows the Mekong Bridge site of National Road 7 at Kampong Cham in the northeastern part of the plain. Sandy deposits are dominant down to 44.5 m from the surface. A gravelly sand layer was found between 16.5 and 19.0 m in depth. The deeper parts show higher Standard Penetration Test values (N-value).

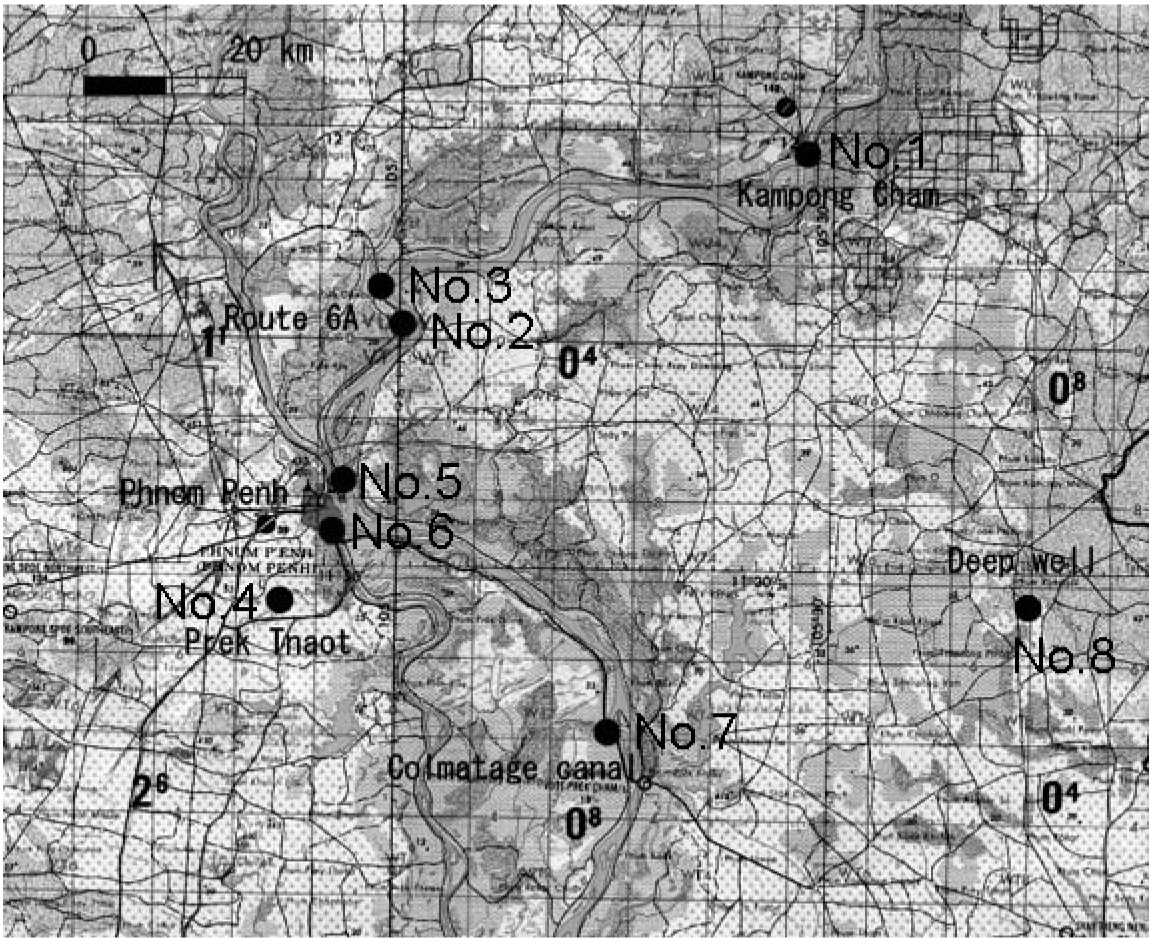

Figure 6a - Bore-hole logs' site map.

Sites No. 2 and No. 3 are located along the Mekong River on National Road 6A, 30 km upstream of Phnom Penh. No. 2 shows a generally clayey profile, whereas No. 3 shows a distinctive sand layer. Weathered rocks occur at depths of 27 m (No. 2) and 29.5 m (No. 3).

Site No. 4 gives test well data from near the Prek Tnaot River. Clay, sand, and gravel layers cover weathered sandstone that appears at a depth of 36.5 m.

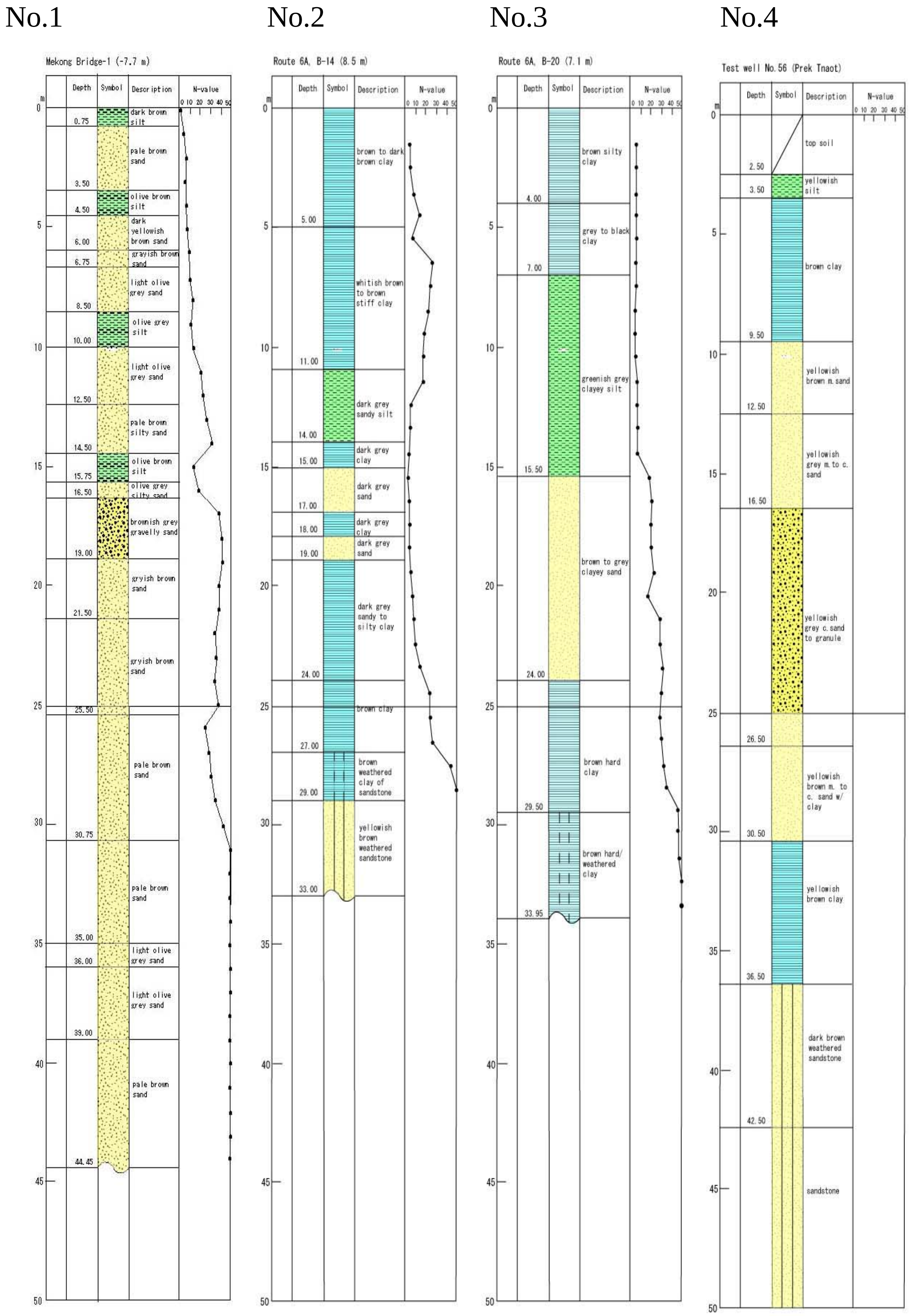

Figure 6b - Bore-hole logs.

In Phnom Penh city, the series of bore-hole data from site No. 5 is from the Chroy Changvar Bridge (the Cambodia-Japan Friendship Bridge) across the Tonle Sap River. Clay with organic material is seen in the upper parts. Weathered sandstone occurs at various depths from 17.4 m (No. 5-2) to 24.4 m (No.5-4), or, -10.5 m (No.5-2) to -26.8 m (No.5-3) in elevation (a.s.l.). On the other hand, in the southern part of Phnom Penh city, base rock was not found within 37-m (No. 6). A soft clay layer lies in the upper 24 m.

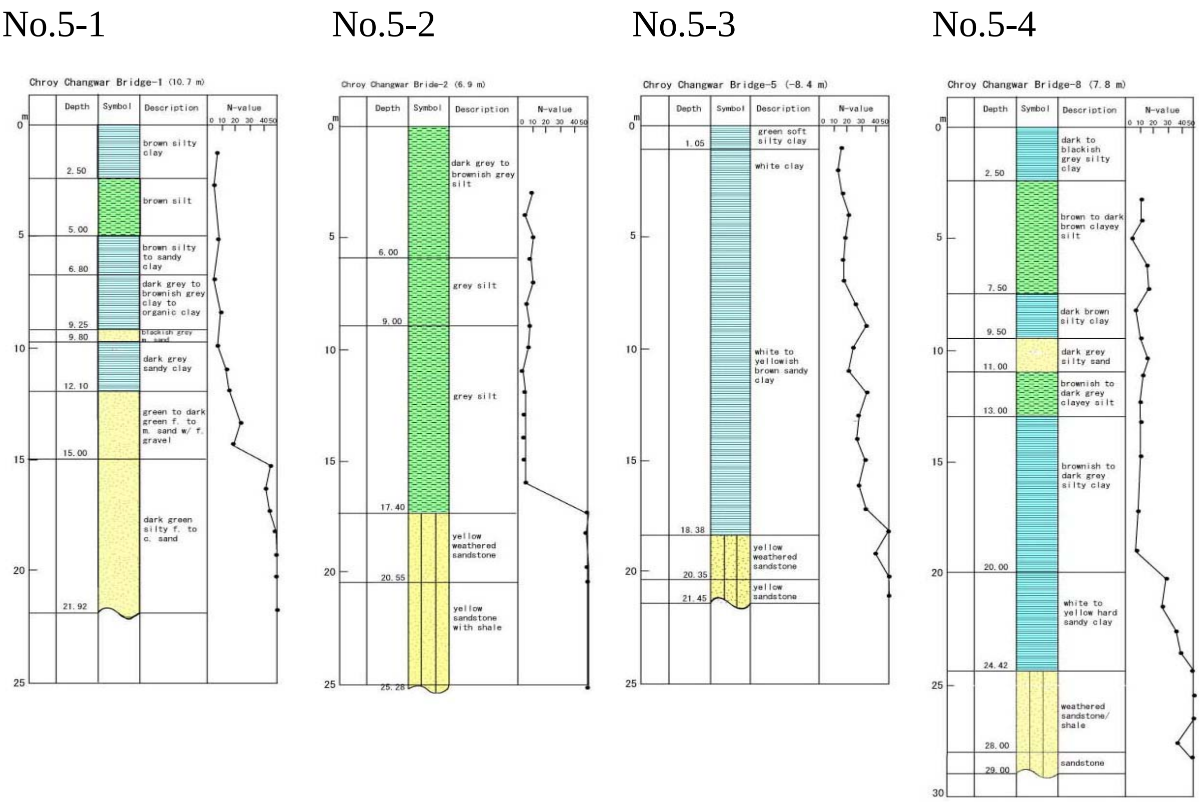

Figure 6c - Bore-hole logs (cont.). Yellow coarse dots: sand and gravel, yellow fine dots: sand, green: silt, blue: clay. Two vertical lines: base rock. Line graph: Standard Penetration Test value (N-value).

Site No. 7 is located at a *colmatage* canal gate along the Mekong River in Kandal Province. Only very soft clay to 35 m depth was seen. N-values are almost zero at depths greater than 12.5 m.

A 135-m-deep test well (No. 8) in Svay Rieng Province shows deposits composed totally of sand and clay.

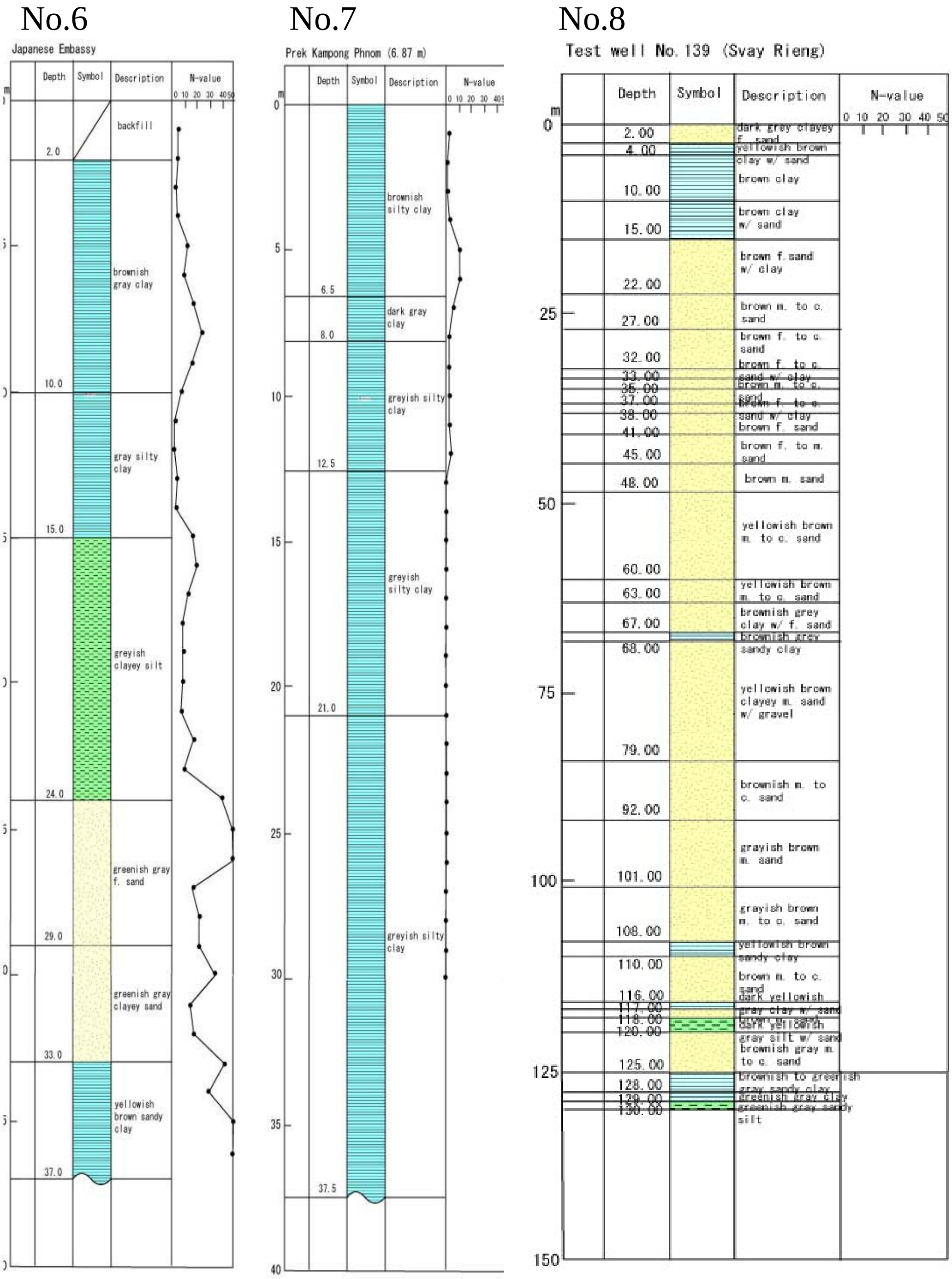

Figure 6d - Bore-hole logs (cont.).

4. DISCUSSION

4.1 GEOMORPHOLOGICAL MAPPING AND FLOOD FEATURES

The micro-landforms identified in the floodplain are a consequence of recurrent floods, and there are close relationships between the areas affected by flooding and these micro-landforms (Oya, 2001; Kubo, 1993, 2002). I previously examined the major geomorphological units in the Lower Mekong Plain in Cambodia and the extreme flooding in 2000 (Kubo, 2004, 2006). This current study uses satellite images from between 1992 and 2002 to reexamine the relationships between the mapped geomorphological features and the analysis of the flooding. The sub-regions below are same as those outlined in section 3.1.

1) Upland, alluvial fan, and residual hill (monadnock) areas. These areas were not inundated in the extreme flood of 2000 or in floods in other years. The gentle alluvial fan of the Preak Tnaot was also generally not inundated, except for its low-lying eastern skirt (within Phnom Penh city). It is because the urban area is located outside the ring dike. Flash floods occasionally occur on this gentle fan.

2) The Mekong floodplain. Along the Mekong River, inundation occurs extensively during every rainy season. The narrow natural levees are slightly higher than the surrounding lands, and normal floods do not reach those parts. However, back marshes function as floodwater channels during rainy seasons. Therefore, any facility in the floodplain that prevents water flow during high-water periods is at great risk.

3) The Tonle Sap River floodplain. During the rainy season the water comes from the Mekong via the channel of the Tonle Sap River. Floodwater also enters the floodplain from the right bank of Preak Mukh Kampul. These specific behaviors of floodwater result in the water velocity and sediment deposition being smaller than that of the Mekong floodplain, resulting in a broad, marshy area.

4) The Bassac floodplain. A number of *colmatage* canals are connected perpendicular to the main river. During the rainy season when the water level increases, water from the main river flows into the canals and drains into the back marsh areas. Simultaneously, sediments are deposited along the *colmatage* channels and form slightly elevated land. Therefore, very little area along the Bassac River was inundated in the 2000 flood. Floodwater moves through the numerous *colmatage* channels into the back-marsh areas, and floodwater does not overflow along the main river channel, so floods here can be well controlled.

5) Slightly higher alluvial surfaces. Normal floods do not reach these surfaces, except the peripheral areas, but large floods do occasionally inundate this area. During the large flood in 2000, the higher alluvial surfaces on both sides of the Mekong were extensively inundated (Kubo, 2003a).

The geomorphological units in the Lower Mekong Plain are confirmed to have close relationships with the areas affected by flooding, with some parts depending on the magnitude of flooding.

4.2 SUBSURFACE GEOLOGY OF THE PLAIN

Geomorphological mapping shows that there is a transition between the floodplain with natural levees and back marshes, and the deltaic plain near the border of Cambodia and Vietnam (Ta et al., 2002; Kubo, 2003a). My study of the subsurface deposits in the plain also supports this argument. In the uppermost part of the plain near Kampong Cham (site No. 1), sandy deposits with gravels are dominant, corresponding to the braided-channel deposits. Deposits along the Preak Tnaot River (No. 4) represent alluvial fan. Near Phnom Penh (Nos. 2, 3, 5, and 6), the surface deposits are clayey and represent back marsh deposits. Base rock occurs relatively shallowly in parts (No. 5). In the lower reaches in Kandal province (No. 7), thick, soft clay going down more than 30 m represents a deltaic environment.

Recently Hori et al. (2007) and Tamura et al. (2007) described drilled cores in the Phnom Penh area. Hori et al. (2007) described 25-m channel-fill and over-bank deposits in an abandoned river channel in the north of Phnom Penh.

Tamura et al. (2007) drilled and obtained a 30.7-m core about 20 km southeast of Phnom Penh. According to them, the upper 7-m-thick part is recognized as a natural levee to floodplain deposits. The facies is reddish brown silt, containing concretions. I observed similar deposits on an outcrop near the Kop Srav Embankment near Phnom Penh.

The underlying facies of the floodplain deposits in the core of Tamura et al. (2007) is salt marsh deposits of alternating peat and graded sand, and has a ^{14}C age of about 7.3–8 ka. However, I did not find any similar deposits in the logs from the southern part of Phnom Penh city or from Kandal Province. The former (Nos. 5 and 6) may lack this because of the shallower basement rocks. The latter (No. 7) has no sandy material but very soft clay; however, a slightly harder part (higher N-value) occurs at depths of between 5 and 7 m, which might correspond to the Upper Sand (US; Kaizuka et al., 1977) or the foreset bed of the delta. The lower layer corresponds to the Middle Mud (MM) or bottomset bed of the delta.

Although the base rocks are shallow in the western part, data from a deep well (No. 8) suggest that the Quaternary deposits are greater than 130 m thick in the eastern part. This suggests the presence of a structural basin and is in accord with a supposed east-dip geological fault running along the Bassac River (Nguyen et al., 2000). However, the monadnock of Mount Ba Phnom lies near the left bank of the Mekong in Svay Rieng Province. Therefore, buried landforms with a considerable degree of relief are estimated to be in the delta region.

The Holocene marine transgression must have reached near Phnom Penh. However, further investigation is needed to clarify its depositional environment and the buried landforms.

5. CONCLUDING REMARKS

I demonstrated the connection between local geomorphological features and flood behavior in the Lower Mekong Plain in Cambodia, and I have discussed the subsurface deposits in this area. The Lower Mekong Plain is the combined floodplain of the Mekong, Tonle Sap, and Bassac rivers. There are local differences in the geomorphic features that reflect differences in the features of flooding in the area. Extensive inundation occurs in the back marsh areas during every rainy (wet) season, whereas higher alluvial surfaces are inundated only during large floods. Natural levees are generally free from inundation. Analysis of satellite images proved the relationship between the magnitudes of floods and the geomorphological units in terms of inundated areas.

Examination of bore-hole logs revealed varied deposits within the plain. Examination of the subsurface deposits suggests a change from sandy braided-channel related deposits at Kampong Cham into clayey back-marsh deposits near Phnom Penh, and the presence of a deltaic environment in the southern part. The base rocks appear shallower in the western part, whereas thick (>130 m) Quaternary deposits occur in the eastern part, suggesting the presence of a structural basin or considerable buried relief. More coring and dating are needed to reconstruct the form of the depositional basin and the extent of the Holocene transgression.

Acknowledgements

I am grateful to the following organizations that kindly provided bore-hole logs: the Ministry of Public Works and Transportation (Cambodia), the Ministry of Rural Development (Cambodia), the Mekong River Commission, the Ministry of Foreign Affairs (Japan), and the Japan International Cooperation Agency (JICA). I also acknowledge Mr. Minoru Kamoto and Mr. Masaru Kawamura, JICA experts, who kindly helped me in Cambodia.

This study was supported by a Grant-in-Aid for Scientific Research No. 13571042 from the Japan Society for the Promotion of Science (2001–2003), and by the Research Revolution 2002 (RR2002) Project of the Ministry of Education, Culture, Sports, Science and Technology, Japan (2002–2006).

6. REFERENCES

Gupta, A. and Liew, S.C., 2006. The Mekong from satellite imagery: A quick look at a large river. Geomorphology, 85: 259–274.

Hori, H., 2000. The Mekong: Environment and Development. United Nations University Press, Tokyo, 398pp.

Hori, K., Haruyama, S. and Sieng, S., 2007. Sedimentary facies of borehole cores from the Mekong River floodplain in Cambodia. Geographical Review of Japan, 80: 681–692.

Kaizuka, S., Naruse, Y. and Matsuda, I., 1977. Recent formations and their basal. topography in and around Tokyo Bay, central Japan. Quaternary Research, 8: 32–50.

Kubo, S., 1993. Geomorphological features of Northwestern Bangladesh and some problems on flood mitigation. GeoJournal, 31: 313–318.

Kubo, S., 2002. Geomorphological features of the Thu Bon River plain, Central Vietnam, and their relations on flood hazards in 1999. Gakujutsu Kenkyu (Academic Studies), No. 50, 1–12, Waseda University, Tokyo.

Kubo, S., 2003a. Geomorphological features and flood characters around Phnom Penh, Lower Mekong River Plain. Proceedings of the 1st International Conference on Hydrology and Water Resources in Asia Pacific Region, Vol. 2: 692–696, Asia Pacific Association of Hydrology and Water Resources, Kyoto, Japan, March 13-15, 2003.

Kubo, S., 2003b. The Lower Mekong River Plain in Cambodia: Landforms and Deposits. Abstracts, XVI INQUA Congress, p.82, Reno, USA, July 23-30, 2003.

Kubo, S., 2004. Geomorphological features, flood characters, land-use and water-use in the Lower Mekong Plain in Cambodia. Proc. of International Conference on Advances in Integrated Mekong River Management, 201–205, Revolutionary Research 2002 Research Group, Vientiane, Lao PDR, October 25-27, 2004.

Kubo, S., 2006. Land, water and land use in the Lower Mekong Plain (Cambodia): Geomorphological integration. Proc. International Conference on “Mekong Research for the People of the Mekong”, 309–316, Mekong River Commission et al., Chiang Rai, Thailand, October 18-21, 2006.

Mekong River Commission, 2003. Social Atlas of the Lower Mekong Basin, Phnom Penh, 154p.

Mekong River Commission, 2005. Overview of the Hydrology of the Mekong Basin, Vientiane, 73p.

Nguyen, V.L., Ta, T.K.O and Tateishi, M., 2000. Late Holocene depositional environments and coastal evolution of the Mekong River Delta, Southern Vietnam. Journal of Asian Earth Sciences, 18: 427–439.

Oketani, S., Haruyama, S. and Sieng, S., 2007. Floodplain characteristics of the Mekong Delta in Cambodia. Geographical Review of Japan, 80: 693–703.

Oya, M., 2001. Applied Geomorphology for Mitigation of Natural Hazards. Kluwer Academic Publishers, Dordrecht, 166p.

Ta, T.K.O., Nguyen, V.L., Tateishi, M., Kobayashi, I., Tanabe, S. and Saito, Y., 2002. Holocene delta evolution and sediment discharge of the Mekong River, southern Vietnam. Quaternary Science Reviews, 21: 1807–1819.

Tamura T., Saito Y., Sieng, S., Ben, B., Kong, M., Choup, S., Tsukawaki, S., 2007. Depositional facies and radiocarbon ages of a drill core from the Mekong River lowland near Phnom Penh, Cambodia: evidence for tidal sedimentation at the time of Holocene maximum flooding. Journal of Asian Earth Sciences, 29: 585–592.