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Eastern Asia Geological Hazards Map: Paper and Digital Versions

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ABSTRACT

The *Eastern Asia Geological Hazards Map* (paper version) and *Interactive Geological Hazard Map of East and Southeast Asia with GeoHazardView* (digital version) respectively were published in 2002 and 2003 by the Geological Survey of Japan (GSJ), AIST. These constitute the first attempts to compile small -scale hazard mapping focused on the geological hazards in eastern Asia. The paper version consists of a geological hazards map of endodynamic origin that includes seismic hazards in particular tsunami and volcanic ones; one sheet of hazards of exodynamic origin partly induced by human activities such as landslides, coastal erosion, and deposition; one sheet explaining the legends, and an explanatory pamphlet. Because of paper version limitations, a digital CD-ROM version was produced to make hazard information readily available both to geologists and the general public. In order to mitigate geological hazards, the general public also needs to be well informed about the problems. The CD-ROM presents all the collected geological hazard information in the mapping project in an interactive way by the use of newly developed GeoHazardView software. The user can access, view, manage, update and enlarge or reduce the scale on the screen at will. To handle both types of maps easily and for better user understanding, the geological hazards are summarized.

1. INTRODUCTION

Damage caused by natural disasters has been increasing and become more serious world-wide, especially in Asia, because of complicated and active natural environments. Such damage is further aggravated by countries' weak and vulnerable social conditions which have been worsened by rapid, uncontrolled socio-economic development. During the latter half of the 20th century, 70 percent of the approximately 5 million people who were disaster victims were in Asia. Mitigating of the effects of natural disasters therefore is a priority in Asian countries. One important aspect of mitigating damage is to make information about natural disasters readily available; not only to policy makers, planners, and professionals but to the general public as well. By doing so, communities will be better informed about devising measures to minimize the loss of lives and the economic impact of natural disasters. Natural hazard mapping and development of relevant databases are indispensable in such undertakings. Distribution of both paper and digital versions of such maps is very important today for people to gain such information as soon as possible because Internet Technology is rapidly developing.

During 1992 the 29th International Geological Congress (IGC) in Kyoto, Japan, Japan proposed an international scientific program for world-wide natural hazard mapping. An international forum next was held in Tsukuba, Japan in 1993 to implement this proposal (Kato, et al. ed., 1994; Kato, 1998). The result of this forum was formulation of the Eastern Asia Natural Hazards Mapping Project (EANHMP) in the GSJ, focusing on geological hazard mapping in the eastern Asia region as the first step. This started in 1994 with the cooperation of the international community. The project was endorsed by the International Decade for Natural Disaster Reduction (IDNDR), the Coordinating Committee for Geoscience Programmes in East and Southeast Asia (CCOP), and the Commission for the Geological Map of the World (CGMW). Its implementation is shown in Table 1. Consequently, the *Eastern Asia Geological Hazards Map* (1:7,700,000) was published in 2002 (Kato and EANHMP, 2002). Although some of the information on geological hazards collected in the project had already been published (See Kato, et al., ed., 1994; Kato and Shimazaki, ed., 1997; GSJ ed., 1998, Kato and EANHMP, 2002), not all could be fully described by means of printed media. To make comprehensive information about geological hazards readily available and accessible to a wide range of users, an interactive digital version of the map, distributed in CD-ROM (GSJ, AIST, 2003) was produced. We introduce the paper and digital versions of this hazard map and provide a brief summary of the geological hazards in the eastern Asia region to help users gain a better understanding of the usefulness of these maps in efforts to mitigate disaster damage.

2. EASTERN ASIA GEOLOGICAL HAZARDS MAP

2.1 Composition

(1) The paper version of the geological hazards map consists of three sheets and an explanatory note. The first and second sheets give historical records of each hazard event with the background geology and qualitative risk probability (prone area). The third sheet presents the legend and brief explanations. The first sheet mainly shows geological hazards of endodynamic origin such as seismic ones, including tsunami and volcanic hazards. The second sheet mainly shows geological hazards of exodynamic origin such as landslides, coastal erosion, and deposition and related phenome-

KEY WORDS: geological hazard, hazard map, seismic hazard, volcanic hazard, landslide, coastal erosion, eastern Asia

Table 1 Implementation of the Eastern Asia Natural Hazards Mapping Project (EANHMP)

June, 1993	International Forum for Natural Hazards Mapping (Tsukuba, Japan)
May, 1994	International Meeting of EANHMP (Yokohama, Japan)
Sep., 1994	First Workshop on EANHMP and International Symposium: Asian Natural Disasters and Hazards Mapping (Tsukuba, Japan)
Sep., 1995	Second Workshop on EANHMP and International Symposium: Sustainable Development of Coastal and Offshore Areas in Eastern Asia (Tsukuba, Japan)
Aug., 1996	Third Workshop and International Symposium on EANHMP (Beijing, China)
Feb., 1997	Fourth Workshop on EANHMP and International Symposium: Geology for Geohazard Mitigation in Asia (Osaka, Japan)
March, 1998	Fifth Workshop on EANHMP (Tsukuba, Japan)
Oct., 1998	CCOP Technical Meeting-Remote Sensing for Disaster Mitigation and Geohazard Mapping (Manila, The Philippines)
July, 1999	CCOP Technical Meeting: Exodynamic Geohazards in East and Southeast Asia (Pattaya, Thailand)
Jan., 2000	International Symposium: Geo-Scientific Development and Hazard Mitigation in eastern Asia (Hiroshima, Japan)
July, 2000	CCOP Technical Meeting: Standardization of Slope Disaster Susceptibility in East and Southeast Asia (Kunming, China)

na. The small-scale map also presents information about regional risk potential, remote source hazards such as tsunami and regional volcanic ash fall, as well as the vulnerability of a given region to compounded hazards.

(2) The digital version of the map (*Interactive Geological Hazard Map of East and Southeast Asia with GeoHazardView*) is distributed as a CD-ROM which has an interactive version of the geological hazards map. The aim of the digital version is to provide more extensive information about geological hazards than is possible in the paper format. The geological hazard maps and related information are presented in an interactive way by means of GeoHazardView software programmed by Joel C. Bandibas of the GSJ, AIST. This CD-ROM has digitized geological hazard maps as well as related geological hazard information such as the data on individual events, photographs of volcanoes, etc. These data can be accessed, managed, viewed, and updated only by using GeoHazardView software installed and run under the Microsoft Windows operating system. The user has the option to enlarge or reduce the scale on the screen using that software. When the user starts the GeoHazardView, the hazards selection mode is indicated on the screen. Concrete individual usage is described in each hazard section as follows.

2.2 Legend of the printed hazard map and its digital version

Small-scale and regional hazard maps that show several geological hazards together against the background of the area's geology and topography and their digitized map are the first trial in the hazard mapping of the world. Therefore it is first necessary to explain the legend and how to compile the maps.

(1) Geological and Topographical Background

The characteristics of geological hazards, their occurrence, type, and susceptibility, are closely related to the geological, tectonic and topographical settings. In this hazard map, the exaggerated topographic features only are represented by shading instead of contour lines because the scale is so small.

The geological legend roughly depends on the stiffness of the ground, as shown in the dialog box of Fig.1 which shows an example scene from the digitized map presenting the main part of Japanese archipelago.

a) Sedimentary rocks: S_1 shows mainly hard pre-Neogene sedimentary rocks; S_2 mainly consolidated Neogene sedimentary rocks; S_3 mainly semi-consolidated Pleistocene deposits including some undifferentiated Holocene sediments; and S_4 mainly unconsolidated Holocene deposits.

b) Volcanic rocks: V_1 shows mainly hard and massive pre-Neogene volcanic rocks; V_2 consolidated Neogene-Pleistocene volcanic rocks; V_3 mainly Quaternary volcanic rocks related to recent volcanic activities, and V_4 undifferentiated Neogene-Quaternary volcanic rocks.

c) Pre-Quaternary hard rocks such as plutonic, metamorphic, ultramafic and associated basic rocks are grouped into one category.

Tectonic features also affect geological hazards. In inland areas, geological faults with lengths roughly longer than 100 km are represented by solid black lines, and inferred faults by broken black lines. Red lines represent active faults, major faults that at least cut Quaternary deposits, and inferred active faults are shown by broken red lines. Fold axes are omitted to avoid complexity. In offshore areas, plate tectonic settings and topographic features reflect accumulated tectonic movements are shown, in particular subduction boundaries that are divided into two groups, erosion and accretion types, because of the effects of gravitational slides on the sea bottom.

(2) Seismic Hazards

Earthquakes are classified by magnitude (M decided by the Japan Meteorological Agency), focal depth, and the number of casualties. An earthquake with a magnitude larger than M7.0 is shown by a large circle on the map; one with magnitude between M6.0 and M7.0 is shown by a medium circle, and one of unknown magnitude by a small circle. An earthquake with a focal depth less than 10km is shown in red, one with a focal depth between 10 and 70km in dark green, one with a focal depth deeper than 70km in purple, and one whose focal depth is unknown in black. The number of casualties is shown by a graded sector inside of a circle. In the digital map, if the user clicks on each circle showing an earthquake, individual earthquake information: latitude, longitude, country of the epicenter, name of the earthquake, date of occurrence, number of casualties, focal depth, magnitude and if tsunami occurred appears. Furthermore, the circle clicked is magnified and pulsates, the maximum magnitude scale being shown by the color of the center. Figure 2 shows an example screen on the digital map. All the collected data are not always shown on the map. For example, in China, earthquakes with magnitudes of less than M7.0 are omitted to avoid complexity. A double circle signifies association with a single tsunami and a triple circle with multiple tsunami events in the past. Because coastal areas attacked by tsunami in the past may again be devastated in the future, where sufficient countermeasures have not taken, locations are called the "tsunami prone areas" and represented by blue along the shorelines shown on the map. In the digital map, the user has the option of measuring the distance between two points by using the pointer mode. This function allows the user to determine the distance (kilometers and miles) jbetween the offshore epicenter of an earthquake and the closest coast on the screen. The arrival time of a tsunami can be calculated if the speed of the tsunami wave. Earthquakes associated with surface ruptures which directly damage man-made structures and which may occur repeatedly at the same adjacent sites also are represented separately. On the digital map, by pulsating the symbol the user can show specified earthquakes selected by range of occurrence times, magnitude, focal depth, locality, numbers of casualties, etc.

(3) Volcanic Hazards

Legends for volcanic activities related to the type and recurrence of volcanic hazard are shown by various symbols on the map (Fig.3). A triangle indicates the location of an active volcano, and its size the intensity of volcanic activity. If the user clicks on a tri-

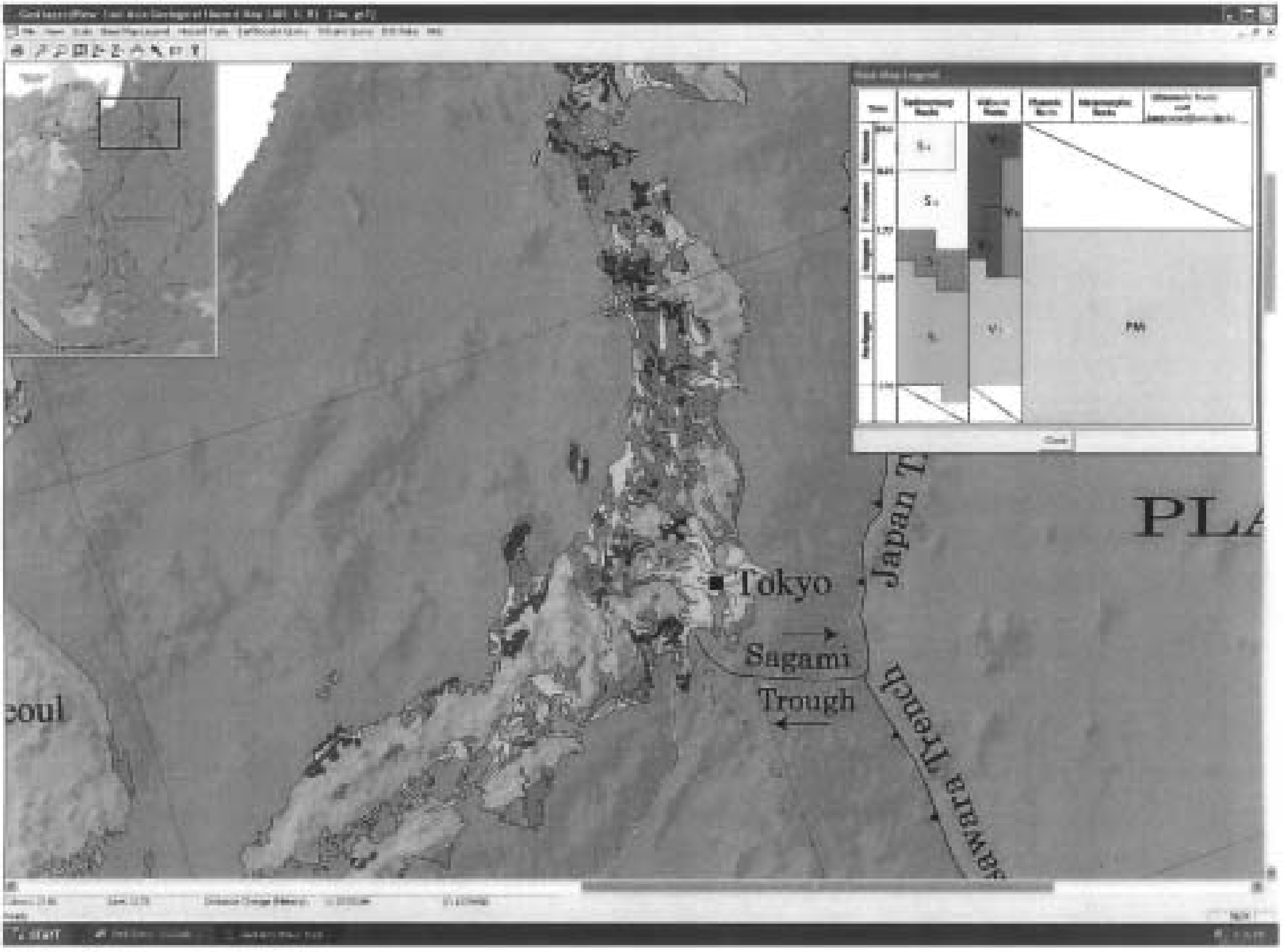

Fig. 1 Geological view of the hazard map (CD-ROM version)

angle in the digital version, the name of the volcano and detailed information of its activity will appear. A triangle colored red indicates volcanic activity with magma eruption over the past 2,000 years. Orange triangles indicate there is no record of volcanic activity. A dot inside a triangle signifies a volcano that is associated with a crater lake and/or snow capped. A circle enclosing a triangle represents a volcano associated with a topographic caldera depression of a diameter larger than 10 km. Broken purple lines delineate areas covered by a large-scale volcanic ash falls in the past 2,000 years. In the overall map, regional ash fall deposit areas during the eruptions of Baitoushan (Paekdusan), Korea in the 10th century, Tambora, Indonesia in 1815 and Pinatubo, the Philippines in 1991 are shown, but they are not presented in Figure 2 because it shows only the main part of the Japanese archipelago. In the digital version, the areas of ash fall spread across the screen with time by means of animation.

(4) Landslide and Related Slope Disasters

Landslides and other slope disasters are the most destructive geological and geomorphic processes caused by restoration of the gravitational stability of the earth's materials. Such disasters may also be complicated by human-induced factors that affect the stability of slopes. On this map, only landslide-prone areas are shown, indicated by solid brown areas because of difficulty in quantitatively correlating the susceptibility of landslide occurrence as proposed by each country's committee. Landslide-prone areas correspond to so-called high and moderate susceptibility zones in which more than 10 deaths have occurred in the past. From qualitative topographical and geological points of view (Fig.4), these zones may give serious social-economic effects in near future,

(5) Coastal erosion/deposition

Changes in natural coast lines depend on balance between the scouring effects of waves and ocean currents and the supply of sediments which also are affected by human activities. Recently, as economic development of coastal areas has accelerated, retreat of coast lines due to erosion has worsened.

In this mapping project, country data about coastal changes could obtained only from China, Japan, and Thailand. Consequently, such coastal types as rocky coasts, sand and gravel ones, sand and muddy ones, coral reef coasts, mangrove ones and artificial coasts are represented instead of quantitative change rates.

3. OUTLINE OF GEOLOGICAL HAZARDS IN EASRERN ASIA

One of the most important ways to mitigate damage by disasters is to enhance awareness of geological hazards and the understanding of them among the public nationally and locally. Because

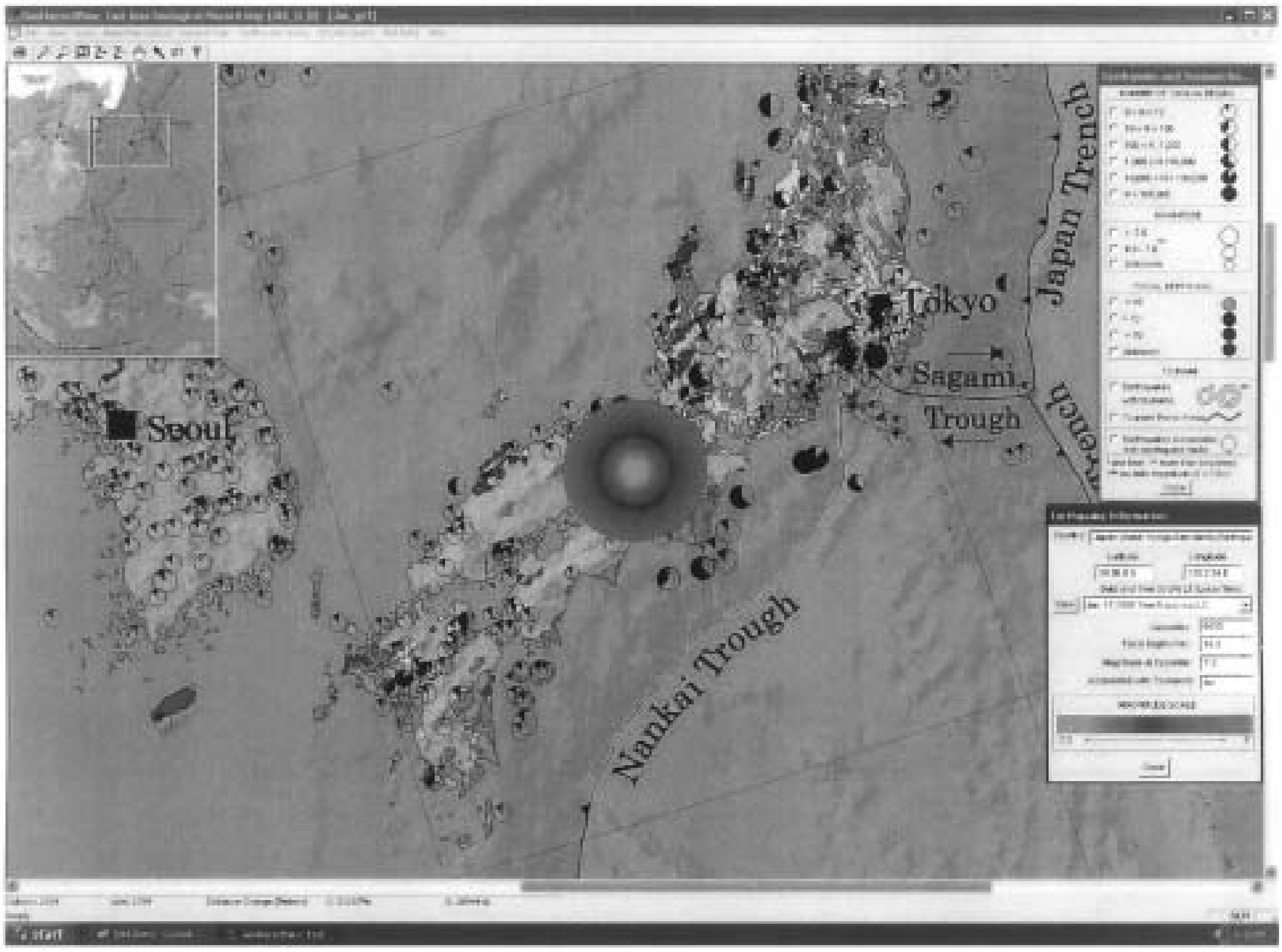

Fig. 2 Earthquakes and seismic hazard view of the hazard map (CD-ROM version)

Eastern Asia communities have common interests about the causes and effects of geological hazards, it is useful to exchange information about the processes, mechanisms, causes and properties of such hazards, and the countermeasures taken even though each countries have characteristic geological and tectonic settings. Moreover, as some geological hazards directly affect areas that cross national boundaries, it is useful to know what geological hazards exist in other countries. Small-scale hazard mapping done in cooperation with concerned Asian countries and relevant international organizations provides the best means of mutual enlightenment. An outline of the geological hazards present in eastern Asia is given in order to understand the hazard maps because continental areas, island arcs, and offshore regions have unique geological hazard characteristics.

3.1 Geological Hazards in Island Arc regions

(1) Seismic Hazards

The island arc regions are located in the most violent seismic zones, rendering them essentially seismic hazard areas because subducting ocean plates along the arcs not only directly cause inter-plate earthquakes with fairly deep focal depths but indirectly cause of intra-plate earthquakes with relatively shallow focal depths and inland active faulting. Inter-plate earthquakes that occur in offshore regions often trigger tsunamis even when their epicenters are far from the damaged coasts. Consequently, most coastal regions of the eastern Asia island arcs have more frequently been attacked by tsunamis as compared to those of Asian continent.

The Japanese archipelago, under which four plates collide has been severely damaged by several types of earthquakes. The Great Kanto Earthquake (M7.9) of 1923, one of the strongest, most destructive earthquakes, is a typical example of an inter-plate earthquake. It caused a huge number of casualties, approximately 142,000. The same type of earthquake is expected to occur in the near future along the trenches on the Pacific Ocean side of the archipelago. The 1891 Nobi Earthquake (M8.0) in central Japan is the severest example of an intra-plate earthquake caused by active faulting. The latest earthquake of this type was the 1995 Hyogoken-nanbu Earthquake (M7.2) in southwest Japan, which resulted in 7,232 casualties, the collapse of more than 140,000 houses, and other types of severe damage such as fires. This earthquake was associated with a 10.5km long earthquake (surface) fault that appeared along an existing active fault whose recurrent activity interval is about 2,000 years, and it directly dislocated houses (Kato ed., 1995). The Japanese archipelago, there has about 1,500-2,000 active faults whose recurrent periods of activities range from several hundreds to a few thousand years. A recent typical tsunami attack in the northernmost part of the archipelago

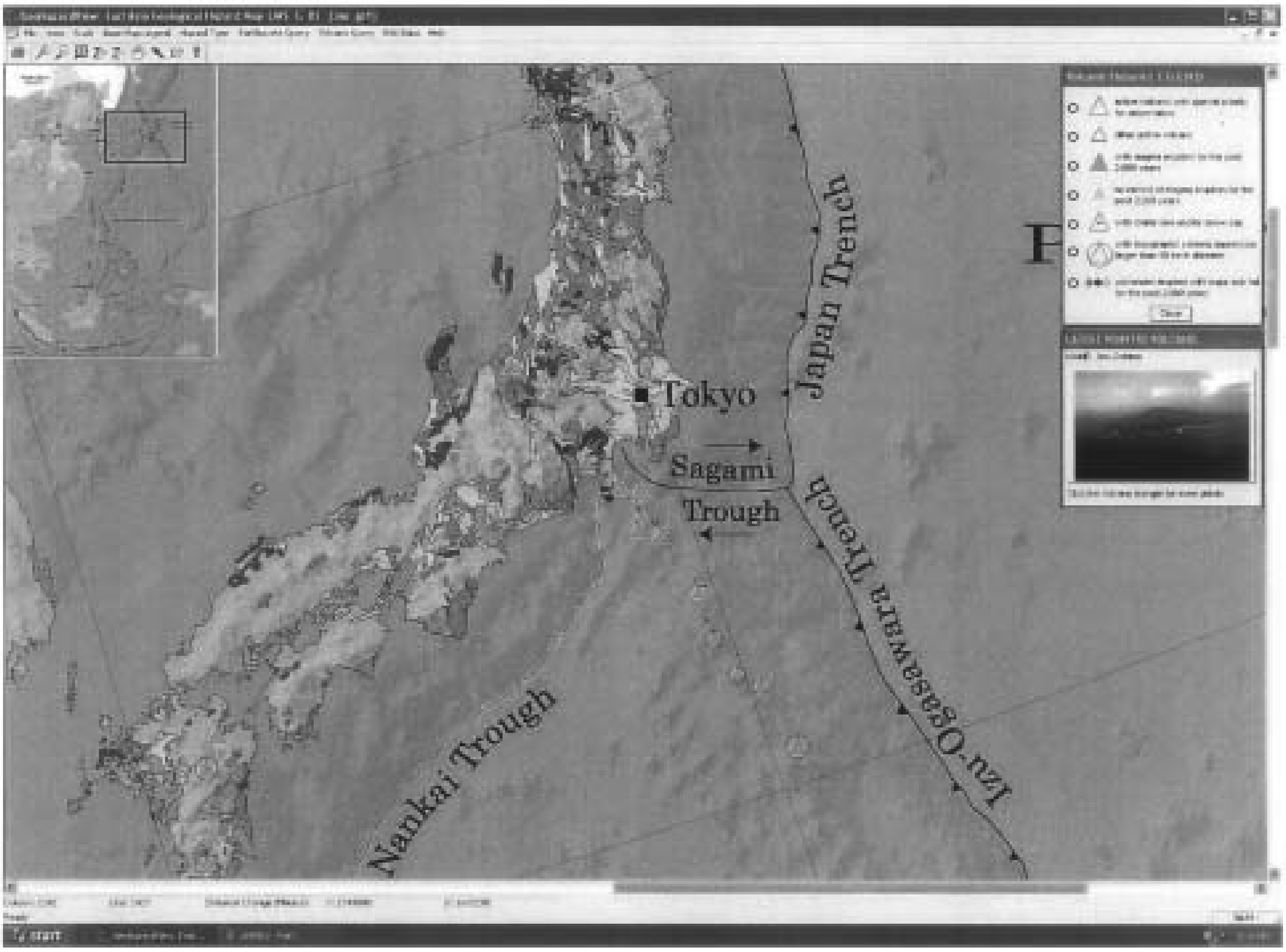

Fig. 3 Volcanoes and their activities of the hazard map (CD-ROM version)

was caused by the 1993 Hokkaido Nansei-oki Earthquake (M7.8). It resulted in 230 casualties and 937 buildings destroyed. That tsunami, with a maximum run-up height of about 30m, struck 4 to 5 minutes after the earthquake occurred.

Neo-tectonic activity and seismicity also are very high in and around Taiwan due to the collision of the Eurasian and Philippine Sea Plates. About 50 active faults extend mainly along the longitudinal axis of the island, and reflect ocean plate motion, but most are not shown on the map because of their short lengths. Throughout the 20th century, Taiwan has had several disastrous earthquakes; those in 1906 (M6.8), 1935 (M7.1), 1941 (M.7.2), and 1951 (M7.0), which were associated with earthquake surface faults. The latest intra-plate earthquake was the 1999 Chi-Chi Earthquake (M7.3-7.6, focal depth 5-10km). It was the result of reactivation of an active thrust fault with a total length of more than 90km. Various kinds of ground deformation were concentrated on the hanging wall of that fault (Lee, 2000).

Earthquake activity in several seismic zones in and around the Philippine archipelago account for more than 3.2 % of the world's activity and is caused by the very active motion of the western margin of the Philippine Sea Plate. (Gupta, 1997). Inland, the most active, 1,200km-long Philippine Fault roughly parallels the Philippine Trench from Luzon Island in the north to Mindanao Island in the south. It caused repeated M7 class intra-plate earthquakes during the 20th century. The average recurrence time of this left-lateral fault is estimated to be from 1,600 to 5,000 years. A recent earthquake along the Philippine Fault was the 1990 one of magnitude 7.8 which caused not only the collapse many buildings but the induction of numerous destructive landslides. Even worse, it is not an exaggeration to say that every earthquake near the Philippines is soon followed by a tsunami.

Because the 6,000km-long Indonesian seismic belt is under the influence of the convergence of the Pacific, Indo-Australian and Eurasian plates, the seismicity there accounts for about 10% of the world's total. An average of about 400 earthquakes occur annually, ten of which are high magnitude ones. Furthermore, inland, the Great Sumatran Fault, a 1,650 km-long, dextral strike-slip fault zone, accommodates part of the oblique convergence of the surrounding plates, causing intra-plate earthquakes. A 300 km-long seismic gap is estimated along this fault (Bellier et al., 1999). Tsunami have always been associated with the main shocks because Indonesia has the longest coast lines in the world, a graben-like basin has developed under the extensional tectonics of the sea floor and hypocenters typically occur beneath the sea floor (Simandjuntak, 1995).

(2) Volcanic Hazards

The island arc regions of eastern Asia are located in the circum-Pacific volcanic zone. Interaction between several plates in

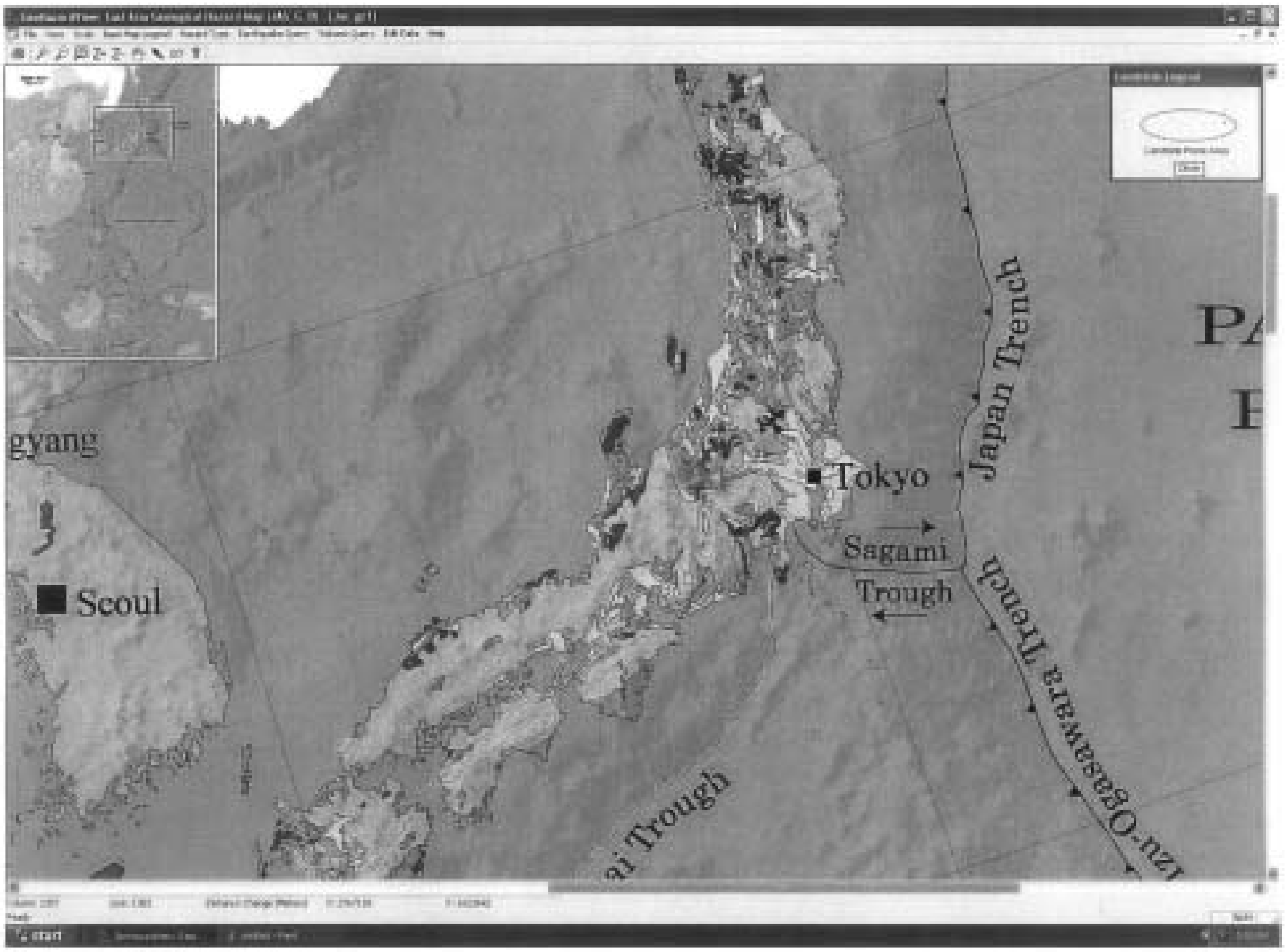

Fig. 4 Landslides and their prone areas of the hazard map (CD-ROM version)

the Quaternary has resulted in remarkable volcanic activities throughout the region. Japan has more than 200 Quaternary volcanoes, of which more than 80 are still active, comprising ten percent of all the volcanoes in the world. There are about 200 Quaternary volcanoes, including 21 active ones, in the Philippine archipelago, and about 129 active volcanoes and 271 volcanic ruins in the Indonesian island arc.

The worst ten volcanic eruptions in Asia, in terms of the number of human lives lost have occurred in Indonesia, with the exception of the 1792 eruption of Unzen volcano in Japan. The eruption of Tambora volcano in 1815 was the worst, resulting in 92,000 deaths and a massive regional ash fall. Although most volcanic hazard is restricted to the immediate vicinity of the erupting volcano, the volcanic ash ejected may travel long distances and cover a wide area. This can affect the flight of airplanes and disrupt regional climatic patterns. Some examples of recent volcanic activities are given hereafter.

In Japan, recent volcanic activities have been vigorous. The eruptions of the Unzen volcano, Kyushu Island from 1990 to 1995, resulted in more than 9,000 dome-collapsed pyroclastic flow events and the deaths of 44 people. In the 2000 eruption of Usu volcano, Hokkaido Island, the first explosion sent a plume 32,000 meters high and ejected about 130 thousand tons of tephra. That eruption caused the evacuation of more than 8,000 people for more than one month. The most recent volcanic eruption in Japan was that of Miyakejima, a volcanic island, far to the south of Tokyo, central Japan. That eruption was associated with a large crater formed on the summit which has continuously emitted SO_2-rich volcanic gas. This caused the evacuation of the island's entire population (circa 3,800 people) in early September 2001. Even now in 2003, none of the evacuees have been allowed to return permanently.

In the Philippines, more than 700,000 people live in the immediate vicinity of various types of dangerous volcanoes. Consequently, significant casualties have occurred in such major volcanic eruptions such as those of the Mayon, Hibok-Hibok, Taal, Bulusan, and Canlaon volcanoes. The most recent catastrophic volcanic eruption was the 1991 Mount Pinatubo Plinian eruption in central Luzon Island. That volcano ejected some 8.4 to 10.4 km^3 of pyroclastic materials which killed more than 400 people and turned into lahar flows that still pose a continuing threat to central Luzon Island (Bornas, 2000).

The volcanic disasters experienced in Indonesia are too many to enumerate, and there are still many active, dangerous volcanoes. The lava of Indonesian volcanoes is andesitic in composition, i.e. the explosive type. More than 50% of the world's victims of volcanic disasters have been Indonesians. In the 19^{th} and 20^{th} centuries, numerous killer volcanic eruptions occurred in the Indonesian archipelago in addition to the eruption of Tambora volcano. The eruption of Krakatau volcano in 1883 killed 38,000 people, and the lahars of the eruption of Kelut volcano in 1919 killed 5,000 people. In 1930, Merapi erupted killing 1,369 people and in 1963 Agung volcano claimed 1,700 lives. Merapi volcano in central Java erupted again in 1994, the heat cloud killing 32 people (Katili, 1994).

(3) Landslides and Related Slope Disasters

The active tectonic island arc regions also have high potentials for landslides because the islands consists of vast hilly and mountainous areas with steep slopes that are made up of various types of geological discontinuities and weak, unconsolidated bedrock. Earthquakes and heavy rainfalls frequently trigger landslides. An example of an earthquake-induced landslide is one that occurred in 1989 along the Sumatra Fault System and killed 120 people. Approximately 300 major landslides occur in Indonesia every year, 30 to 40 occurring during the annual monsoon season. Such landslides caused the deaths of several hundreds of people in the latter half of the 20th century. In recent years, human activities for agriculture and human settlement in hilly and mountainous areas where are usually on unconsolidated volcanic materials have induced debris slides and slumps. An example of a human-induced landslide is the 1987 one caused by quarrying in West Sumatra that took 130 lives. A landslide caused by cutting slopes for the expansion of settlements occurred in 1985 in West Java and killed 37 people (Siagian, 1998).

In the Japanese archipelago, which is seventy percent mountainous, the occurrence of landslides is strongly affected by geological and tectonic settings. One of the most devastating types of avalanche is caused by large-scale rapid catastrophic slope failure sometimes associated with composite volcanoes (volcanic rocks) and high relief mountainous regions that have Pre-Tertiary accretionary terrains. Another devastating landslide type is caused by slow sliding and creep. It occurs in areas where clayey soil is underlain by mudstone, tuff, hydrothermal-altered volcanic rocks, or serpentine. Landslides also occur in semi-consolidated clastic materials of the Neogene. These areas are associated as well with reactivated slow slides of mudstone and rapid slides of gravels and sandstone. It is characteristic that enormous landslides are closely related to uplifting that took place during the Quaternary (0.5 to 1 Ma). For example, the 1985 Jizukiyama landslide, which killed 26 people, occurred in central Japan where the mountainous region shows the highest uplifting that took place during the Quaternary. That slide was 350 meters wide, 700 meters long, and had a volume of $3.5 \times 10^6 m^3$. This type of mass movement is associated with such geological and tectonic settings as active faulting but in that case heavy rainfall directly triggered the landslide.

(4) Coastal Erosion/Deposition

Island arc regions have very long coast lines because they are comprised of many islands. Change in status is balanced by the scouring of waves or ocean currents and by sediments supplied by rivers as well as by human activities. For example, the total coast line length of the Japanese archipelago is approximately 33,000 km. Changes in the 9,500 km sandy coast line are closely related to littoral drift induced by incident waves and long shore currents. The advance and retreat of coast lines respectively add up to changes of more than 1 meter and less than –1 meter per year. Stable coasts have changes within the 1 to –1 meter per year range. Tanaka et al. (1993) found that the coast lines of the islands of Hokkaido in the north and Okinawa in the south of the archipelago, are the most severely eroded coastal areas in Japan. In Osaka Prefecture, the second largest in Japan, an artificial coast has been developed, and the lengths of its retreating sandy coast line and the natural sandy coast line are the shortest in Japan. Isobe (2000) pointed out that the potential for coastal erosion has been very high since 1978 because of various development projects and industrial activities in Japanese coastal areas.

3.2 Geological Hazards in the Continental Region

(1) Seismic Hazards

Seismic activity in China is characterized by high frequency, large magnitude, and extensive distribution. Typical intra-plate earthquakes cause severe damage because of their shallow focal depths. Over the past 3,000 years, nearly 10,000 earthquakes have occurred in China, 60% of them destructive. The most recent disastrous earthquake was the 1976 Tangshan Earthquake (M7.8) which claimed about 240,000 lives. The average interval for a strong earthquake with a magnitude of 8 is about 13 years, whereas earthquakes with magnitudes of 7 to 7.9 occur at 2 to 3 year intervals. On the average, earthquakes with magnitudes of 6 to 6.9 occur every year. According to Ding (1994), in China there have been more than 715 earthquakes within the last 90 years, that have caused about 614,680 casualties. Although tsunami are relatively rare on the Chinese mainland, in the past, Taiwan frequently experienced tsunamis. Twenty-five tsunami attacks were recorded in the whole China from 47 B.C. to 1966, 8 to 9 of which were destructive (Shi, 1995).

In and around the Korean peninsula, seismic activity related to tectonic structures such as the Yangsan and Ulsan active faults in the southeast of the peninsula is not very severe and earthquakes usually of a magnitude of less than 4 having occurred. Historical records, however, report a disastrous earthquake in 779 that claimed more than 100 lives as well as tsunami in 1643, 1668, and 1681. In 1993, the East Sea tsunami with a maximum run-up height of 2.57m devastated the eastern coast of Korea.

In Vietnam and adjoining regions, their older tectonic frameworks have been reactivated during recent geologic times because they have been affected by tectonic movements of the Himalayan-Indonesian and West Pacific mobile belts. Seismic activities in North Vietnam most frequently are recorded along active NW-SE trending faults. In the 20th century, there were 2 earthquakes with intensities of 8 to 9 (Ms=6.7) and some 20 earthquakes with an intensity of 7 (Ms=5.0-5.6). Most occurred in mountainous zones, where the population density is very low and resulted in very low damage. At present, although the seismic hazard in Vietnam is not severe, it is expected to worsen because of the rapid expansion of urban areas and concentration of the population in industrial centers which may be located in high seismic activity zones (Nguyen Dinh Xuyen,1994; Tran Van Tri, 1997).

Myanmar lies on the border of the Alpine-Himalaya seismic zone, and historical records show that remarkable earthquakes have occurred throughout the country, except in coastal areas. Owing to a low population and the absence of multi-storied buildings and infrastructures, past strong earthquakes did not cause great loss of property or human lives (Swe, 1994). As the other continental countries of Laos, Cambodia, Thailand and (Peninsular) Malaysia are located on ancient rigid blocks in rather non-active tectonic settings, most have escaped the severe damage.

(2) Landslides and Related Slope Disasters

In Korea, landslides result in an average annual loss of 60 lives. Most are triggered by rainstorms from July to September and often are induced because construction works have created unstable slopes. (Lee, 1994).

In China, landslides represent the largest type of slope disaster in terms of scale. Individual landslides have a volume of more than generally 10,000 m^3, and the biggest may have 1 billion m^3. The oldest reported landslide, which occurred in 186 B.C. in Wudu, central China, killed 760 people. By A.D.1989, the number of casualties caused by landslides was at least 257,000. These landslides generally were triggered by earthquakes, very heavy rainfall, or flooding caused by the failure of dams (Ding, 1994; Li and Wang, 1992). Slope disasters brought about by debris flows also have caused severe damage. A typical recent example occurred in Dongchuan City, Yunnan Province. From 1965 to 1985, debris flows occurred 10 to 28 times per year on the average, a totally 260 such flows. The average volume of materials transported is about 1 to 3 million m^3 per year, sometimes as much as 5 million m^3. The primary causes of debris flows are the weak geological and active tectonic settings.

In Vietnam, slope disasters occur in mountainous areas in the northern and central regions of the country. Detailed information on these slope disasters, however, is not available at present.

In Cambodia, landslides also occur in hilly and mountainous areas but recent attention have focused on landslides along the Mekong River's banks where social and economic development has been remarkable. The magnitudes of Cambodian landslides normally are higher during the rainy season (Boly, 1997).

In Thailand, landslides mainly occur in mountainous regions owing to a combination of high relief and high precipitation. For example, the debris flow slide of 1988 in southern Thailand, triggered by a major rainstorm, claimed 100 lives (Harper, 1993). The most severely affected area lies in a zone of deeply weathered granitic rocks with a thickness of 1 to 10 m. If the areas damaged by that extensive landslide had not been deforested, the landslide volume would have been 20 to 30% less.

In Malaysia, excessive precipitation and human activities, such as road construction, changing the water level of reservoirs, and mining operations are the main external factors during the heavy rainfall season, many deep-seated slides occur in colluvial deposits and on some hill slopes with heights of up to 50 meters. Most of the rockfalls in peninsular Malaysia occur in limestone hills and rock overhangs along road cuts (Mohamad, 1994).

(3) Coastal Erosion/Deposition

On the Korean peninsula, the eastern coast, comprised of Paleozoic and Mesozoic sedimentary rocks, is more resistant to erosion than is the western coast comprised mostly of Precambrian metamorphic systems and Mesozoic granites. The western coast, total length about 17,300 km, is characterized by gently undulating and small hilly areas with a large but shallow alluvial plain. It is very irregular because of the presence of many islands, embayments and tidal flats. In contrast, the eastern coast region is more mountainous, its valleys being deeply incised and short, and it is characterized by curvilinear, steep-sloped headlands. Narrow coastal plains are present only in and around rivers' mouths. At the mouth of the Nakdong River, since construction of a dike to control water flow, a sand bar near the coast has migrated seaward, indicative of coastal erosion and a lower supply of channel sediments due to artificial human effects (Lee, 1995).

The continental coast line of China is about 18,000 km long, and there are several thousands of islands. Most coastal cities are located in delta areas (Ha, 1995). This is serious because not only do the deltas protrude into the ocean, submerged deltas are washed away by strong ocean currents. The old Yellow River delta has the highest retreat rate of all the coastal deltas in China, erosion increasing on the south and north sides of the old Yellow River mouth. Lately, human activities have become the most important factor in coastal erosion. For example, along the Dengzhou shoal, the coast has disappeared completely because of the fishery industry (Guo et al.,1995).

The coast of Cambodia, which is about 435 km long, is shallow, the average depth being 50 m. Forests of mangroves and rear mangroves separate the land from the sea along sheltered coastal sites where sufficient muddy sediments accumulate. Nearly 80% of the coastal area is still undeveloped. The absence of heavy industrialization lessens the danger of pollution and other coastal hazards produced by human activities (Panhasith, 1995).

Thailand has a coast line approximately 2,600 km long. Severe coastal erosion has been caused by both natural and human factors. One of the most serious natural hazards is tropical cyclones which create coastal erosion, mostly along the southeastern coast of the peninsula. The rate of coastal development, related mostly to industrial and tourism projects, during the past two decades has been increasing and will continue to increase in the future. This has led to conflicts over preservation of the environment vs. development. For example, the land subsidence induced by human activities along the upper edge of the Gulf of Thailand has led to coastal erosion in the Bangkok area (Sinsakul, 1997).

(4) Karst collapse

Karst collapse and sinkholes occur when ground water with dissolved CO_2 corrodes and erodes carbonate rocks. They, therefore, depend greatly on the geology of the area and other natural factors such as rainfall and the occurrence of earthquakes. Karst collapse also can be hastened by such human activities as the over withdrawal of groundwater, mining, and reservoir construction. Karst collapse is not shown on the printed hazard map (data is included in the CD-Rom version) because of correlation difficulty, so it has been summarized here for the convenience of users.

In continental China, karst collapse has occurred in 19 provinces, and 225 cities or counties. Totally 807 karst areas, 88% of which are covered with loess soil, and 45,771 sinkholes have been found. The Yunnan-Guizhou plateau and south China hill-basin plain karst province have been the areas most severely damaged by karst collapse. The largest sinkhole in China, in Yanguan, Shanxi has a diameter 300m and a depth of 600 m (Institute of Hydrogeology and Engineering Geology, 1989; Wen et al., 1996).

In Thailand, highly potential karst areas are concentrated in the southernmost part where Permian limestone predominates. Moderate potential karst areas are found in the middle of the country where Ordovisian limestone is the dominant formation.

In Malaysia, highly potential karst areas with predominate outcrops of limestones are present in Kuala Lumpur, Ipoh, and Bau (Ramli, 1997).

(5) Land subsidence / Ground subsidence

Land subsidence is a geological process that also may be caused by human activities such as excessive extraction of groundwater. This phenomenon has become very destructive in Asia and has accompanied remarkable socio-economic development. Although land subsidence is not shown on the printed hazard map (data is included in the CD-Rom version) because of difficulty in collecting data from all the concerned countries, it has been summarized here for convenience of users.

In China, a total area of 1,500 km^2 is affected by land subsidence, and thirty-seven cities, including Beijing, Shanghai, and Tianjin (where 5 km^2 has dropped below sea level) have suffered severe land subsidence. The fastest subsiding region is Tanggu-Hangu in Tianjin, with a subsidence rate of about 188 mm/year. Subsidence in that area ranged from 2.18 to 2.6 meters between 1989 and 1992 (Guo et al.,1995).

In Vietnam, land subsidence has occurred in the urban areas of Hanoi, Hochiminh City, on the Red River, and on the Mekong Delta. Land subsidence in coastal areas results to salt water intrusion, groundwater pollution, and swamping.

In Thailand, Bangkok and its adjacent areas have been severely affected by land subsidence owing to the excessive withdrawal of groundwater. From 1987 to 1996, Bangkok sank at the average rate of 5 to 10 cm per year, the maximum being 83.3 cm from 1987 to 1992 (Ramnarong and Buapeng,1992).

In Malaysia, land subsidence caused by groundwater extraction and compaction of underlying, unconsolidated sediments also is very common in predominantly limestone areas and in areas developed on soft and paludal deposits (Ramli, 1997).

4. CONCLUSION

The remarkable increases in damage caused by geological hazards in eastern Asia in recent times are due to complicated and active geological and tectonic settings in the region and haphazard land-use planning and utilization in most countries in this region. The current rapid economic development of these countries increases the likelihood of more widespread destruction of property and the loss of human lives due to future geological hazards. One of the most effective ways to mitigate damage caused by geological hazards is to make people better informed about the phenomena; policy makers, decision makers, politicians, educators, and ordinary citizens. The small-scale geological hazard map is a very useful tool to better inform these people about these destructive phenomena because the paper version presents several types of geological hazard information in regional areas at a glance and the digital version provides an interactive, fascinating way to handle hazard information. We believe that these maps will become milestone contributions to hazard mitigation in Asia.

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