PART ONE

OVERVIEW OF THE STATUS OF URBAN GEOLOGY IN ASIA

I. THE STATE OF GEOSECURITY IN ASIAN CITIES

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Introduction

The rapid development of urban areas in Asia has generated concern with regard to the scope and extent of their infrastructural and environmental problems. The end of the 20th century has seen an unprecedented change in the area and population of Asian cities. City authorities in Asia are 'utterly committed to continuing growth' now just as they were in the United States of America 30-40 years ago (Flawn, 1970). Almost without exception, there has been a worsening of environmental conditions in the great metropolitan areas of Asia, which contain four of the ten largest cities in the world, Tokyo, Dhaka, New Delhi and Mumbai as well as more than a hundred cities of over 1-2 million. The Asian Development Bank (1988; 1993) has summarized the situation as follows, "In 1950, there were only 19 cities in the region with a population of one million or more. By 1970, the number had grown to 49. By 1990, as many as 86 cities in the region were classified as metropolitan areas. By the turn of the century, 12 of the 21 megacities in the world (each having a population of 10 million or more) will be in this region". This paper summarizes the work of the region's Geological Surveys with respect to urban geology and shows how such organizations can be more effective in working with all of the stakeholders involved in urban development. The Geological Surveys of Asia have a more important role to plan in urban development in the future. They should devote a considerable amount of their resources to using their expertise to make urban areas safer places to live. The Geological Surveys need to be aware of the newest emerging social issues that affect the health and living conditions of our urban populations in order to focus their expertise in the most important areas.

1. Geosecurity

There has been a considerable amount of attention given to the problem of developing cities that are able to mitigate risk from environmental hazards and damaging geologic events such as earthquakes. One approach that has proved successful in many western countries for more than thirty years and that has shown promise during the last two decades in Asia is the application of geologic knowledge to planning and development of urban areas, a field of geology that has been termed urban geology and which we prefer to call *geosecurity*. In order to encourage a continuation of these efforts, the Economic and Social Commission for Asia and the Pacific (ESCAP) has provided training and technical assistance in developing this approach in 25 countries of Asia since 1985. The main focal points within the governments of the region have been geological surveys but professionals from other agencies concerned with city planning and managing the environment have been invited to participate whenever possible and some joint meetings have been held. The main issue is – how best to accommodate orderly development and growth while protecting urban populations from natural hazards, ensuring public health, clean air and safe water while minimizing degradation of our natural and man-made environment.

2. The ground beneath our feet

The past two decades have seen major strides taken towards improving the knowledge base of ground conditions in the region's major urban centres. There has been a significant increase in the use of geologic information to make thematic maps that show the advantages of using geology in city planning. Governments have exchanged information on how to mitigate the impact of natural disasters and produced maps that help planners guide the expansion of cities away from hazardous zones and into areas that have more favourable ground conditions for urban development. Moreover, some progress was made in making urban planners more aware of the value of subsurface resources. Some now realize the importance of mapping the ground beneath the city in order to identify scarce resources and protect valuable sand and gravel resource areas as well as groundwater recharge areas from being built over or spoiled by pollution. In short, in order to live in harmony with nature, we now recognize that appropriate urban geologic data such as geological maps and their derivative thematic data needs to be compiled and presented in a form that will help city fathers understand "the ground beneath our feet".

A. Vulnerability of Asian urban areas

Many large cities have expanded into unsuitable and hazardous areas because these were the only available options. However, many more cities have grown into areas with high risk simply because of ignorance of geologic conditions even though other safer areas were available. Unfortunately, the cities that ignore the consequences of such actions pay a price in treasure and blood. In Asia, many large cities are vulnerable to land subsidence, flooding, earthquakes and other natural disasters for two important reasons. Firstly, the capitals of Japan, the Philippines, Thailand, Indonesia, Viet Nam, Myanmar, Bangladesh, Papua New Guinea and Cambodia as well as many large coastal cities of China are built on soft and poorly drained deltaic soils. Secondly, many of the coastal cities lie on or near the unstable Pacific Rim, a setting that is vulnerable to severe tropical cyclones and typhoons. Many Asian cities are affected by severe earthquakes because of their proximity to the plate boundary between the Pacific and Eurasian plates. A few have been severely damaged by volcanic eruptions (Japan, the Philippines, Papua New Guinea and New Zealand) and tsunamis (Japan, Bangladesh, India, Indonesia, Papua New Guinea, and the Philippines). Cyclonic storms have severely flooded virtually every major city situated on the Pacific coast and the Indian Ocean at one time or another.

The impact of geologic processes and damaging natural events on cities became one of the concerns of governments about two decades ago when ESCAP initiated an urban geology programme in 1985. One of the first tasks of the programme was to document the extent of vulnerability and risks in Asian cities.

1. Asian tectonic setting

Many cities of the region, especially those in South, South-West and Central Asia, lie on active fault zones, former sutures, located in the Asian continental interior. These zones stretch westward from India to Turkey following the Himalayan, Tian Shan, Pamir, Altay (Altai) and Zagros ranges through Pakistan, Nepal, Bhutan, Tajikistan, Uzbekistan, Afghanistan, the Islamic Republic of Iran, Iraq, Turkey, Turkmenistan, Kazakhstan, and Azerbaijan. For example, some of the larger cities that are vulnerable to earthquakes generated along these zones are Chiang Mai, Yangon, Dhaka, Kolkata (Calcutta), New Delhi, Lucknow, Chandigarh, Kathmandu, Islamabad, Quetta, Lahore, Dushanbe, Bishkek, Spitak, Ashkhabad, Kabul, Kandahar, Tashkent, Samarkand, Almaty, Baku, Tehran, Tabriz, Ankara, Istanbul and Izmir.

The tectonic history of Asia is of vital concern to geologists working to mitigate the risk from earthquake events. The recent tectonic history of the interior of most continents is stable but this is not the case in Asia. Large intracratonic earthquakes in the interior of India, China, the Russian Federation and many Central Asian Republics are not uncommon. One need only note the 6.5 magnitude earthquake that struck the eastern margin of the Deccan trap, 400 km east of Mumbai, on September 9, 1993, killing 15,000 people and leaving 32 villages totally destroyed. This was the worst earthquake to hit India in 250 years yet it was unmarked by any prominent fault zone apparently originating from a buried fault in the Precambrian basement (Limaye, 1993).

Dangerous active faults are common in the suture zones of the Himalayan mountain chain located in the northern part of South Asia and southern China. The trace of the North Anatolian fault zone in South-West and Central Asia is the location of some of the most severe earthquakes that affect this region. The region's plate tectonic history has brought together a patchwork of micro- and macro-plates that have collided with the Eurasian plate to form the Himalayas and Pamirs, unstable ranges that now lie in the deep interior of the vast Asian continent. Many of the plate boundaries in the region are still tectonically active. Consequently, the interior of Asia has a much more active tectonic regime than either North America or Europe. The continent of Asia also has more megacities situated in geologically hazardous terrain than any other. The very large earthquakes of the 1980-1990s in Asia, primarily in Turkey, the Islamic Republic of Iran, the Russian Federation and Central Asia have inspired renewed efforts to understand the region's tectonics. This activity can be compared to the early earthquake studies and concerns of how to mitigate the risk from quakes that arose in the United States of America in the 1960s (Steinbrugge, 1968; Association of Engineering Geologists, 1965; Kockelman, 1977 and others). Even though the interior of North America is relatively stable (with a few notable exceptions), its west coast has suffered from many destructive earthquakes and valuable lessons have been learned there that are applicable to mitigating earthquake risk in Asian cities. Several major international cooperation programmes are in place in some of the most affected countries.

2. Geotechnical issues

About one-half of all Central Asian urban residents, three million people, live in buildings that are highly vulnerable to earthquakes as a result of their location and design. South-West and Central Asian governments were concerned with the earthquake-resistance of their present building stock, mostly constructed in the 1950-1960s. Many buildings of Central Asia fall into a standard structural type and earthquakes of the late 1990s (Neftegorsk-Sakhalin) and the 1980s (Spitak-Armenia) have shown that the earthquake-resistance of these structures is poor. On 28 May 1995, a 7.2 magnitude earthquake killed 60 per cent of the population of Neftegorsk, mostly due to collapsed buildings. On 7 December 1988, a 6.8 magnitude earthquake killed 25,000 people in Spitak and nearby towns, mostly as a consequence of poor construction practices (Erdik, 1997). A large percentage of the urban population of Central Asia uses urban structures that are not built strongly enough to resist the types of earthquake disasters that are relatively common in this region. At the time these buildings were constructed, there were no detailed geologic maps of the urban areas, although many cities of Central Asia had been leveled by earthquakes more than once (e.g. Almaty, Bishkek and Ashkhabad), even though earthquakes of $M \geq 7$ were uncommon. Unfortunately, some of these cities were rebuilt without too much concern for recurrent major earthquake events because of their rarity in terms of a human lifespan. Unfortunately, a number of exceedingly large earthquakes have occurred and recurred within a period of one or two decades killing tens of thousands along well known fault zones in Central and Western Asia (e.g. Turkey). The magnitudes of these quakes even surprised earthquake specialists.

In North America, the detailed mapping of the geology of urban terrains must include an assessment of their geologic conditions, mineral and water resources, and the engineering properties of their subsoils. Such data have proven invaluable in the planning and development of urban areas there. For example, the Los Angeles Department of City Planning (1974) had emphasized the important role of ground shaking in causing building collapse during a moderate or major earthquake more than twenty-five years ago. Shaking causes "the greatest amount of damage from earthquakes occurring in rather populous areas". Structural failure results from "...(i) shaking which damages the structure directly, (ii) shaking which causes soil failure beneath the foundation of a structure, and (iii) shaking which causes the soil beneath the foundation to densify and settle, thus causing the structure to fail". Consequently, the two most important types of maps for a city planner in an earthquake prone area are (i) a map of the city that shows, at a relatively large scale, the types of soils and their engineering properties and (ii) another map that shows the levels of ground shaking that can be expected based on data from past earthquakes. Such maps would allow cities and districts to establish more restrictive building and development policies and criteria such as decisions similar to those made by the City Council of Los Angeles that, for example, could be incorporated in city planning guidelines everywhere in Asia. Another concern is building on or near the trace of an active fault. The Los Angeles code reads as follows. "...[no] structure for human occupancy...shall be...placed across the trace of an active fault...". Consequently, one of the ultimate goals of any urban geology programme should be to have every active fault clearly shown on city planning maps. Second, legislation should be in place to prevent certain types of structures from being built in the fault zone areas.

Mountainous topography makes up a large proportion of most Asian countries far more than it does exist in the United States, Canada and Europe. Consequently, ground failures are a major concern. Warm, wet climatic conditions, sometimes augmented by seismic events are responsible for many landslides. There is a large maintenance commitment in keeping highways open in the Himalayas, Malaysia, Taiwan Province of China, Indonesia, the Philippines and Hong Kong, China as well as many Pacific Island countries such as Papua New Guinea and Timor-Leste.

3. Asian coastal setting

In heavily populated East and South-East Asia, 75 per cent or almost *1.5 billion people*, live in the coastal zone (Asian Development Bank, 1988). Some of Asia's largest cities are located there and virtually every capital and many large cities in these two regions, save Beijing and Seoul, are located near or on the coast (ESCAP, 1985). If an examination were to be made of the environments of these cities, it would be noted that they share a similar geologic and hydrologic setting and are prone to disastrous floods and tropical storms, which can be categorized as hydrologic hazards. Those that lie in active tectonic belts are prone to earthquakes and volcanic eruptions (ESCAP, 1985; 1986; 1990; and 1991). Many cities would be inundated by only a one metre rise in sea level (Bird, 1983a; 1983b). There have been many excellent studies made of the impact of geological processes on coastal urban development and these have served at best to mitigate the impact of some of the problems and at the very least have provided food for thought for decision makers and engineers that face the task of planning and constructing coastal works and cities (Brown and Kockelman, 1983; Kockelman, 1977; 1985; Blair and Spangle, 1979; Davis et al., 1982; ESCAP, 1995c and 1999; Fisher, 1972; Hillen, 1991; De Mulder and Hageman, 1989; McCall and others, 1996; Hageman, 1989; Geological Survey of the Netherlands, n.d.; Spangle Associates, 1976; and United States Geological Survey, 1981). The use of these types of data for land use planning in coastal tracts in Asia is still developing but has improved markedly in the past decade (Rau, 1994).

4. Coastal hazards

Tropical storms have flooded cities in China, the Philippines, Japan, Thailand, Cambodia, Viet Nam and Bangladesh annually leaving rural and urban residents huddled in shelters, or even on boats, sometimes for months at a time (ESCAP, 1991). Many urban areas of the coast are poorly drained and face severe erosion problems in spite of man's best efforts to construct levees, breakwaters, storm drains and floodways. Sometimes city engineering departments did not realize that groundwater exploitation was creating a subsidence bowl beneath the city. The only obvious fact was that these cities were becoming increasingly difficult to drain after floods and heavy rain storms. Many coastal cities are affected by subsidence due to exploitation of groundwater. In addition to hydrologic hazards, many countries of the region that frequently suffer from severe earthquakes and volcanic eruptions are particularly vulnerable in the coastal area where subsoils are soft and ground acceleration and movement is much greater than in areas underlain by bedrock. Clearly, cities built on rock such as Singapore and Kuala Lumpur are more stable than those built on silt and clay such as Tokyo and Osaka.

Storm surges in the Indian and Pacific oceans are more devastating than ever as a result of man's removal of coastal defense systems (mangrove forests, reefs, dunes, barrier islands and beach ridges). In the past decade, more than 50 severe storms, including up to five typhoons a year, have struck countries such as the Philippines, Cambodia, Viet Nam, China (especially in Hong Kong, China and Taiwan Province of China), southern Thailand, coastal Bangladesh, and south-eastern peninsular India. Unfortunately, the highest annual death tolls from such events occur in Bangladesh, one of the poorest countries of the region.

Coastal deltas

The coast of East and South-East Asia has numerous large deltas, which have been built into the East and South China seas. The deltaic areas are underlain by soft sediments, which are costly to develop because of their thick silt and clay sequences, sensitivity and low load-bearing capacity. Detailed mapping of Quaternary sediments is essential for development of such areas, and this is one of the most important accomplishments of three programmes which were implemented in the 1980s and 1990s. A major Quaternary mapping training programme, supported by the Netherlands was implemented in South-East Asia through the Committee for Coordination of Joint Prospecting of Mineral Resources in Offshore Areas of Asia (CCOP) in the 1980s. Several International Geological Correlation Projects (IGCP) were active in Asia supporting all types of Quaternary studies (e.g. IGCP Project 296). In the past two decades, every Geological Survey in South-East Asia has received training in Quaternary mapping of coastal plains and deltas. Their staffs are well prepared to undertake such studies at present. More mapping needs to be done simply because these deltas are so large and heavily populated. Good progress has been made in China (Ma and Guo, 1985, Jiang, 1990, Huang and Ge, 1991), Thailand (Dheeradilok and Kaewyana, 1983), Malaysia (Suntharalingam, 1983), and Indonesia (Apandi and Wiriosudarmo, 1999). Groundwater has been over-exploited resulting in a dramatic lowering of the water table (and the potentiometric surface in artesian aquifers) (Broadus, 1988; Nutalaya and Rau, 1981). Several capital cities are sinking below sea level. For example, Bangkok, Jakarta, Manila, and many other coastal cities in China and Japan are still subsiding (ESCAP, 1985; 1988). Many of Asia's coastal areas are being monitored for possible subsidence problems. Subsidence has been mitigated in Shanghai and a number of cities in Japan (e.g. Tokyo, Chiba, Osaka, Niigata and Nagoya) and China (e.g. Changzhou, Tianjin and Ningbo) (Sun and Liu, 1988; Lin and Wang, 1988; Liu and Sun, 1988; and Yamamoto, 1988). The Asian Institute of Technology programme has been one of the most successful in identifying and monitoring Thailand's subsidence problem and graduate students have studied subsidence in a number of other cities as well. Very restrictive policies are now in place to control groundwater development in Bangkok.

Coastal zone management

Industrial development has polluted the land and water quality has been degraded in many cities in India and China. Sediment loads have virtually clogged estuaries to the point that some are no longer useable to deep draft ships in China and Viet Nam. The cost of keeping estuaries open by dredging to allow boats to proceed upriver to reach inland ports has become almost prohibitively costly to a number of Asian countries, the better known examples being Hanoi and Ho Chi Minh cities in Viet Nam, both fighting the silt loads of the Mekong and Red river respectively. Living space has been lost due to coastal erosion, a major problem in China, Viet Nam and Bangladesh. The quality of coastal life is deteriorating due to sediment and chemical pollution of nearshore waters in Thailand and Indonesia. Coastal lands have been mismanaged because population growth has exceeded the capacity of the land to cope with pollution loads and through the promotion of agricultural activities such as shrimp farming or the development of coastal processing centres for hydrocarbon and chemical products. Resource conflicts have created a powerful negative impact on development – yet development forges ahead with little heed of the technical and social consequences.

Resource use conflicts

Coastal zone disputes over land use have arisen among both public and private entities, especially in South-East Asia, reaching alarming levels in the past two decades. The main resource conflicts are between the following sectors: tourism, industry, mining, agriculture, forestry (mangrove harvesting and deforestation) and fisheries. Such disputes over the way coastal land should be used can be bitter and long lasting, seemingly irresolvable. Opportunities to use proper environmental technology and geological input have been missed due to piecemeal approaches to coastal problems. Tourism is one sector that seems to be more aware of the preservation of the natural settings, beaches, pristine waters etc. and, consequently, has taken great interest in promoting the understanding of natural processes that impact on their developments, being most concerned with coastal erosion. Good progress has been made in Malaysia and Thailand (Wong, 1988). A number of manuals have been written to handle the planning and development of coastal and nearshore areas (reefs) as well as the terrestrial and marine resources of interest to the tourist industry (ESCAP, 1992; Baudl-Bovy and Lawson, 1977). The issue of how to manage the environment and sustain growth in the tourism sector of the coastal zone has been reviewed in a number of excellent publications (Wong, 1995; Ecologically Sustainable Development Working Groups, 1991; USAID, 1993).

Natural hazards

Coastal erosion has become a major problem in East and South-East Asia as almost the entire coastline is “soft”. The populous coastal states can ill afford to lose any of their precious coastal land, yet, if the anticipated sea level rise of one metre occurs over the next century or two, the prospects for many Asian shores are grim (Brunn, 1966; 1988; Bualia, 1989). Surprisingly, even though attempts have been made to transfer coastal protection methodologies to Asian countries, e.g. polder technology, the management of a soft coastline is still an enigma in Asia even though these techniques have been practiced for years in the West, especially in the Netherlands and the United States (United States Army, 1975). Natural hazards such as tsunamis, earthquakes and storm surges are taking a greater toll of life than ever before. Long parts of the coastline of Thailand, Malaysia, Indonesia and Viet Nam are in full retreat (Sinsakul, 1990; Nguyen, 1994; Bird and Missen, 1990; Bird, 1986; Bird, 1989; Hobbs, et al., 1981; Praseno and Sukarno, 1977). Important coastal defense systems are being removed due to land conversion schemes, which are replacing mangrove forests with shrimp and fish farms. The deforestation of hinterlands has resulted in increased sedimentation problems and river management is increasingly difficult.

The rising level of city problems related to their rapid growth and the paucity of natural resources that a city needs to survive and the rate of world urbanization over the last two decades all have stimulated the development of the present urban geology programme by the United Nations. The main issue was to mitigate the risk of developing urban lands and to reduce losses from damaging natural events through providing the tools necessary for planners and engineers to understand ‘the ground beneath our feet’. Today the scope of the programme is much broader than mitigating the risk from geologic events but includes the development of basic tools that can be used to build environmental and geologic databases in our cities. In addition to the hazards that exist from earthquakes and other natural hazards, there are no less serious problems related to pollution due to air, water and solid waste contaminants. These pollution hazards are largely unseen and unperceived by urban populations. Air pollution can be just as deadly as a major earthquake over the long term, killing 18,000-20,000 people per year in only one of the cities studied.

The Governments of the Asian region have emphasized their recognition of the problems of urbanization by devoting more resources to improving conditions in the large and intermediate sized cities. For example, Habitat II (Istanbul) emphasized that the most important urbanization issues included shelter for the poor, food supply and protection of the environment and the assurance that the living conditions in rural and urban areas are sustainable. In Dialogue 6, the diversity of the land and settlement patterns throughout the world was noted and it was emphasized that there was a need to find solutions locally and culturally specific (UNCRD, 1996). It has been difficult for planners to avoid the recognition that geology should be part of these efforts.

B. Urbanization in Asia

At the start of the new millennium and for the first time in history, more people live in cities and towns than in rural areas. More than 50 per cent of the population of the capital cities of South and South-West Asia live in squatter settlements that are extremely vulnerable to seismic risk and flooding and because of their lack of basic urban service, cause serious groundwater and surface water pollution (ESCAP, 1985, 1990, 1993, 1995; ESCAP and UNDP, 1996).

Housing problems are still a major concern throughout the region but those problems are closely related to the high rate of population growth and the inability of poor people to provide adequate homes for themselves. Moreover, unregulated growth frequently has resulted in more people living in low-lying areas vulnerable to flooding and other damaging events. Areas of high risk have been identified in most cities but social pressures overcome the will of Governments to restrain growth. More needs to be done to mitigate the impact of geologic processes and events that recur at known probability rates and kill tens of thousands of people each year as well as creating health problems for millions more.

C. The urban poor

Although wealth has accumulated in countries, there has also been steadily increasing poverty in Asian cities. Today, one out of four people in cities lives in "absolute poverty", while another one in four is classified as "relatively poor". Not only do these people have inadequate shelter and lack sufficient and proper food, they also cause and must also live amidst environmental problems of their own making. The results of poor disposal of domestic waste are cause for alarm among those living in nearby areas that fear they will be affected by sanitation problems generated in the poor communities. Many of the environmental problems are related to the inability of municipal governments to control development of squatter communities as well as haphazard industrial development. No matter where squatters locate, they cause urban environmental sanitation problems that have a serious impact on both surface and groundwater. Consequently, squatters themselves are affected by conditions that render their local water resources unsuitable for domestic consumption and for many other domestic uses as well. They also endanger other communities that rely on the same sources of water downstream. The ground beneath urban communities that have large squatter communities was becoming more seriously contaminated each year and water resources, especially groundwater, are made more toxic as time passes. Groundwater pollution was a particularly serious problem in many South and South-East Asian cities and it will not go away until urban poverty has been reduced.

The urban poor in developing countries are virtually helpless in the face of threatening environmental problems: lack of access to clean water, absence of sanitary liquid and domestic waste disposal, accumulating garbage, and a lack of energy sources. The following statistics indicate the plight of the world's poor:

- The World Health Organization (WHO) estimates that 25 to 30 per cent of urban residents in Latin America, Africa, and the Middle East lacked access to potable water (WHO, 2001);
- More than one-third of the people in Asia were not serviced with potable water nor was a significant percentage of wastewater treated properly or at all.

D. History of the development of urban geological studies in developing countries of Asia and the Pacific

In most developing countries of Asia, interest in urban geology began in the early and mid-1980s (ESCAP, 1985) about 15-20 years after such studies had begun in the United States and Europe. However, many aspects of urban development related to engineering geology required in investigations of civil works had been studied since the turn of the century, if not before, always in an engineering context.

1. Birth of urban geology

Early concepts

The term 'urban geology' seems to have been coined by the United States Geological Survey (McGill, 1964). However earlier geological studies of cities have been carried out in the United States by the Geological Survey since the 1950s and continued with more emphasis into the early 1960-1970s (Schlocker, Bonilla and Radbruch, 1958; Trimble, 1963). The impact of geology on urban development was investigated as early as the 1910-1920s in the United Kingdom (Sheppard, 1912; Sherlock, 1922). By the 1990s, the British approach utilized sophisticated databases and computer applications (Ellison et al., 2001). There were a number of California studies that recognized the significant impact of subsidence on urban development in the 1940-1950s, although these studies were mostly by engineering companies with geological input and the work was never referred to as 'urban geology' (Harris and Harlow, 1948, Stone, 1961). Many papers focused on California's urban landslide problem in the 1950s and 1960s (Eckel, 1956; Jahns, 1958; Leighton, 1966), its earthquake problems (Leeds, 1966) and its coastal engineering concerns

(Slossen, 1966). California became the world's showplace for mitigating damaging geological events through urban geological and geological engineering studies.

Development of urban geology in the United States

Perhaps the earliest studies of 'urban geology', as we would now define it, were undertaken in the early and mid-1960s in Boston, Massachusetts by the United States Geological Survey (Kaye, 1967 and 1968; McGill, 1964, Carter, 1967 and others), but very similar studies with thematic maps, termed terrane studies, were undertaken in Australia by Keith Grant about the same time, although most of these maps did not focus on urban areas (Grant, 1965 and many more reports of a similar type) and in Canada by R.F. Legett (1962, 1968, and 1973). About the same time, extensive geological studies of Anchorage and Valdez, Alaska (Dobrovolny and Schmoll, 1968 and others), San Antonio and Houston, Texas, the latter affected by fault problems around salt domes (Bauer, 1966; Van Siclen and DeWitt, 1967; Weaver and Sheets, 1962), Austin, Texas (Flawn, 1966; 1970; Carter, 1967) and the Texas coastal plain (Texas Bureau of Economic Geology – Fisher, McGowen, Brown and Groat, 1972). The Texas coastal study was perhaps the first compilation of detailed 'resource' maps for environmental planning of a large region in the United States. Urban studies were also undertaken in a number of Midwestern states such as Kansas and Missouri (Missouri Geological Survey, Lutzen and Williams, 1968). A large urban geology programme was begun by the Illinois Geological Survey focusing on the Chicago area in the mid- and late-1960s (Frey, 1968; McComas, 1968; Hackett, 1968). Many states picked up the theme in the 1970s including Alabama and Colorado (Hilpman, 1970). The California urban mapping programme emphasized the application of engineering geology and was greatly expanded and spear-headed by the Association of Engineering Geologists, the California Division of Mines and Geology, and the continuing and accelerating urban work by the United States Geological Survey as earthquake concerns, subsidence and coastal erosion among other hazards all became more important (e.g. Radbruch, 1967).

Early geology related environmental and urban books

Significant books also appeared about this time including those of Legget (1962); Flawn (1970), McHarg, a landscape-architect, (1972) and Jahns (1968). Chapin (1965), a planner, produced a book that showed the concerns of planners but seems to have been ignored by geologists as it is rarely made reference to in geologic reports. A classic study appeared in 1971 which was jointly prepared by the United States Geological Survey and United States Department of Housing and Urban Development entitled *Programme Design for San Francisco Bay Region Environmental and Resources Planning Study*. Two other early studies with particular relevance to planning drew attention; they were titled 'The Community Builders Handbook' edited by J.R. Mckeever (1968) and Environmental Planning and Geology by Nichols and Campbell (1971). An eye-opening paper by Evans (1966) noting the impact of injected wastewater on urban earthquakes that were shocking Denver's population in the early 1960s became a pet lecture topic of almost every American geology teacher. In retrospect, the 1960-1970s was the hay-day of American urban geology and more than 12 books were published on the subject of environmental geology which always included at least one 'urban geology' type chapter, commonly titled as land use planning. The efforts to produce useful information for planners culminated with the publication of *Nature to be Commanded* in 1978, a classic collection of United States Geological Survey reports and maps on urban geology (Robinson and Spieker, 1978).

European development

The European approach was led by the Dutch who used their worldwide acknowledged Quaternary expertise to focus on coastal areas and its application to planning (Hageman, 1963; 1989). A major focus on the geology of rail, road and energy corridors was led by Canada in the early 1980s (Weir, 1981; Lawrence, 1989). For a complete review of the application of geology to urban planning in Canada see White (1989). Thematic maps were introduced in Germany in the late 1970s (Lüttig, 1978). By the early 1980s, many such maps were in common use throughout Europe. European aspects of urban geology and examples of environmental geological problems are reviewed in Archer and others (1985).

Asian development

In the 1960s, urban geology in Asia was virtually unknown. Two countries, India and Pakistan, included environmental and/or urban geology as a priority in the 1970s, just about ten years after environmental geology was attracting strong interest in the United States and Canada (Geological Survey of India, 1980). One good example is Operation Anantapur, a highly professional study of a large urban area in southern India, with excellent maps, which was the first programme of the 'integrated, multi-disciplinary studies in the field of environmental appreciation and management for urban planning and development' beginning in 1971 (Raju and others, 1979). However, the Indian studies seem not to have attracted much interest by urban planners and many studies were considered 'confidential'. Most of this work was never expanded into a full-fledged programme nor were atlas type publications produced. A similar situation existed in Viet Nam in the early 1980s, when one-of-a-kind hand-coloured thematic maps of Hanoi were available only on a 'need-to-know basis'. An 'early effort' related to urban geology including the publication of a text with several coloured thematic maps was made in Pakistan (e.g. Quetta), where an outstanding study was published by the Geological Survey of Pakistan (Khan and others, 1986). The Geological Survey of Pakistan's study of Quetta is perhaps the first truly professional urban geology study in Asia because of its large scale thematic maps. These studies were initiated in the late 1970s or early 1980s before the ESCAP programme began.

History of ESCAP programme

In 1985, the Natural Resources Division of the Economic and Social Commission for Asia and the Pacific (ESCAP) introduced the concept of urban geology in three papers presented to the Committee of Natural Resources (ESCAP, 1985). These documents received a surprisingly warm response by none other than J.A. Katili, then Director General of the Indonesian Directorate of Mineral Resources, who also chaired the 1985 annual session of ESCAP's Committee of Natural Resources meeting in Bangkok. Since then, the Geological Surveys of the region have been active in developing a methodology for the application of appropriate geologic information for the rational development of their cities. ESCAP termed this specialty '*urban geology*'. ESCAP developed one of the first urban geological advisory and training programmes in the United Nations system in 1985. A programme was also underway in UNESCO focusing on Europe. The ESCAP work has continued for 17 years and almost every member country in East, South-East, and South Asia as well as one Pacific Island country were involved and had participated in many of the activities of this United Nations programme. The technical contributions of member countries to the programme have been published as a series entitled *Atlas of Urban Geology*, which culminates in the present volume, number fourteen. A total of more than 200 technical papers were published by the United Nations in this series over the period 1985-2002.

Early work in the urban geology programme at ESCAP was focused on the mitigation of natural disasters in general and especially those that impact on urban populations (earthquakes, volcanic eruptions, landslides and land subsidence). In the past ten years, the ESCAP urban geology work programme has focused on using the appropriate technology to compile and assess urban geodata in a format that planners and decision makers could utilize without a background in geology.

ESCAP approach

The approach that ESCAP used to promote the benefits of the utilization of geology in urban planning has been threefold. The first goal was to record case histories of what had gone wrong (but also including success stories). The second was to promote geodata collection, evaluation and presentation in a format user-friendly to planners. The third was to highlight inherent problems of interdisciplinary and interdepartmental exchange of information and promote "horizontal", rather than "vertical" communication (ESCAP, 1999). In 1993, ESCAP established the Forum on Urban Geology in Asia and the Pacific (FUGAP), which has had five major meetings in the past eight years; papers of the last two meetings of the Forum are published in this volume. The Forum consisted of 20-25 member countries that jointly agreed to undertake technical training in the mapping of the geology of urban areas and to raise the level of awareness of the benefits of utilising urban geology in Government agencies responsible for planning the development of fast growing cities.

Many member countries in South-East Asia have recognized the importance of urban and environmental geology by forming special units, sections and divisions within their Geological Surveys. The United Nations urban geology programme in Asia has provided expert working group meetings, workshops, special training and supported technical advisory missions to 25 member countries. The work has been funded by the United Nations and several developed countries with in-kind support from 25 member countries. Moreover, there is a keen interest in the programme on the part of the public as shown by the number of emails received by the ESCAP web site.

Central Asia

Beginning in 1987, a series of advisory missions were fielded to South-East and Central Asian countries. The last advisory mission in 2001 visited India, Uzbekistan and Turkey (chapters III, IV, VII-XI in this volume). Studies were undertaken of the capital cities of Azerbaijan, Kazakhstan, Uzbekistan, the Islamic Republic of Iran and Turkey in South-West Asia in 2001-2002. A special study of Hyderabad-Secunderabad, one of India's new hi-tech areas, was conducted to assess the types of problems faced by medium-sized cities of peninsular India. Recently, Viet Nam and Cambodia have set up an urban geology divisions within their Geological Surveys Department. In mid-2001, Mongolia had requested assistance from ESCAP in the setting up of a similar unit in its Geological Survey (see chapter XXXIX in this volume).

South-East Asia

Viet Nam has made a large number of urban thematic maps, mostly unpublished, for its three largest cities, Hanoi, Ho Chi Minh City and Danang, most of this work beginning in 1988-1990. Subsidence in Hanoi has been a concern for the past ten years but was not the most important cause of its drainage problems, which are largely due to an ineffective storm drain system dating from French colonial time. The city is flooded every year because of its low-lying position behind the 10-metres high dikes that line the Red River. Viet Nam has requested international assistance in a study of the hydrogeological conditions that impact on regional and urban development in the lower Red River delta, and is especially concerned with the environmental conditions of its foremost tourist area and World Heritage Site, Ha Long Bay. The Lao People's Democratic Republic had a small programme focusing on its capital city, Vientiane, in 1998. Thailand had two major projects in the 1990s, one focused on Chiang Mai in the north and the other on Surat Thani in the south.

South Asia

Bangladesh and India recently have expressed concern with the impact of arsenic poisoning on the people of the Bengal delta and this problem has become a major concern for action by the WHO. The Geological Survey of Bangladesh (GSB) with assistance from ESCAP and the United States Geological Survey, embarked on a major urban geological programme in mapping the soil conditions and geomorphology of low-lying areas in the south fringe of its capital, Dhaka in 1993 as well as three other of its larger cities. This work continued until 1999 has culminated in the publication of a number of thematic maps of Dhaka, the capital. Now, the GSB has been designated the prime country-wide focal point for providing data on the geological framework of the delta and, especially, its hydrogeology in support of the country's major drive to mitigate the impact of arsenic poisoning.

East Asia

In China, a geologist has referred to urban geology as "social geology" because it makes city people more environmentally secure, a major goal of the Government. China has taken major steps to launch detailed mapping of the geology of virtually all of its large coastal cities. In the 1980s, some of the early work of the Ministry of Geology and Mines (now Ministry of Land and Resources) had focused on solving the land subsidence problem in China's fast growing coastal cities, especially Shanghai where subsidence was impeding economic development in the delta. China's diverse urban geologic settings have tested the ingenuity of its geological profession resulting in the development of a wide variety of thematic maps useful for planning (ESCAP, 1988; 1995). A recent success was the role of geologic data in a decision to relocate Shanghai's airport that resulted in the saving of almost US$ 2,000,000.

E. Geological mapping of urban areas and current problems

Health issues

The Geological Surveys of the region are moving strongly ahead with their urban mapping programmes. In some countries, the Geological Surveys have been able to convince decision makers that urban geological mapping is necessary to improve the security of the people living in cities as well as for the protection of the country at large because in most of these cities the economic activities generate from 25-30 per cent of the wealth of the country. Especially good progress has been made in Bangladesh, China, India, Indonesia, Malaysia, Nepal, Pakistan, the Philippines, the Republic of Korea, Sri Lanka, Thailand, Turkey, Uzbekistan and Viet Nam. Engineering geology, an integral component of urban geological mapping, is well developed in most of these countries.

In the past two years, health issues related to toxic elements such as arsenic have come to the fore in India, Bangladesh and Myanmar. For example, the rural poor are affected more severely by arsenic poisoning than people in large metropolitan regions because many families rely on untreated tube well water. The identification of contaminated aquifers is a job for the Geological Surveys in these countries and their work in identifying the distribution and depth of contaminated aquifers would be a great benefit to the rural poor. This is an example of how geological data, if properly compiled in the appropriate format, can be a very important method in alleviating health risks that affect people living in poverty and by improving the quality of life of people living in vulnerable areas.

Engineering issues

There is an urgent need for planners and engineers to understand the characteristics of the city's sub-soils and foundation properties in advance of development. The Geological Surveys need to become more active in organizing seminars and workshops for other agencies in order to present their information on an annual basis. Planners have to become more aware that the materials the city needs to grow, e.g., sand and gravel, brick clay, and other building materials should be mapped and zoned properly so that they can be developed in a cost effective way. If the city spreads over these resources, they are sterilized reducing any opportunities for their future development.

Engineering geologists need to work more closely with planners and earthquake engineers in South-West and Central Asia. The building codes probably need to be revised as a result of recent information resulting from large magnitude earthquakes in Turkey and the Islamic Republic of Iran. In general, the Geological Surveys in South, South-West and Central Asia recognize their obligation in this respect and have taken, without exception, notable strides in improving their capacities to provide useful geological information to the planning and engineering professions. But there are many other state and municipal agencies that could benefit from the use of these data.

Mapping issues

Geological mapping can be closely linked to the theme of land management, which was investigated in Habitat II held in Istanbul (United Nations, 1996). It was noted that many aspects of urbanization, e.g. land use planning, could not proceed without knowledge of ground conditions. Habitat II agreed that the cities of this century should employ urban growth models that take full cognizance of the importance of protecting their populations from natural disasters and should conserve the resources that lie beneath the city such as its pure groundwater as well as other scarce mineral resources.

F. The present report

In 2001, the Economic and Social Commission for Asia and the Pacific (ESCAP) sanctioned a mission by a consultant to study selected cities in South, South-West and Central Asia. The mission had a threefold purpose: (i) to conduct a regional survey of urban and environmental geological problems emphasizing South and Central Asia, (ii) to identify the presence or absence of countermeasures taken by the Geological Surveys and other central/local authorities to protect cities that were vulnerable to natural disasters or from expanding into areas of unsuitable subsoils and (iii) prepare a regional overview of problems encountered due to urban geological conditions and steps, which the governments have taken to avoid such problems in the future.

Parts One and Two of this book were written by the ESCAP consultant, Jon L. Rau, a former United Nations geologist (1983-1991). These urban studies were based on field work and interviews of engineers, planners, and geologists in seven cities (Calcutta, Hyderabad-Secunderabad, and Mumbai in India; Ankara and Istanbul in Turkey; Tashkent and Samarkand in Uzbekistan) and desk studies of three cities (Almaty, Kazakhstan; Baku, Azerbaijan; and Tehran, Islamic Republic of Iran).

G. The future of *geosecurity data*

The rapid growth of our cities and the landslide of geologic data that is engulfing the files of the Geological Surveys throughout the world requires a new approach. Consequently, the application of computerized data banks and the presentation of data in a Geographic Information System format have come to the fore. Many of the large cities in the region are beginning to compile databases that include geologic information but the one of the most important needs is for more detailed mapping of the Quaternary geology, hydrogeology and engineering geology of urban terranes at appropriate scales. Peter Flawn (1966) was one of the first geologists to emphasize the need for large scale geologic maps of American cities. He wrote, “To me, it is a fantastic truth that most cities do not have a geologic map and do not employ a geologist. The use of a geological consultant (except on special problems) is not the solution. What is needed is continuing geological supervision to permit day-to-day accumulation of data so that the city can take advantage of and exploit its terrain foundation materials, and resources. In particular, the geologist’s job should be the construction and maintenance of an accurate large scale geologic map of the city. Such maps will pay for themselves time and time again, and for the geologist as well”. Perhaps one way to attract the attention of the public to the value of these data is to retitle them as ‘*geosecurity data*’ because the protection of the urban citizenry has become the major urban issue of the 2000s.

H. What approach should we use now?

Some of the tasks that the Asian geological profession will face in the next two decades include the following types of studies:

- Use geotechnical data to analyse and assess seismic ground-motion site response. The general goal of seismic microzonation is to reliably quantify urban seismic hazard and risk (loss potential) by accounting for the variations in shaking levels due to near-surface geological differences.
- Use the data collected from seismic microzonation studies to make deterministic earthquake scenarios and probabilistic ground shaking maps. Studies should focus on areas where no large earthquakes have occurred but where abundant geologic evidence exists for the past occurrence of surface-faulting earthquakes of moment magnitude (M_w) 7 or greater, particularly along faults that can be traced through urban areas. Participate in interagency teams that review the

impact of earthquakes, make post-earthquake surveys and develop new provisions for earthquake hazards reduction programmes.

- Develop an urban dynamics research programme that can assess the land use changes in urban environments. The types, timing, causes, extent and impact of landscape changes need to be monitored using remote sensing techniques. The data are needed for studies of urbanization, resource extraction, and water resources development. The prime data sources would be topographic maps, historic city maps, census statistics, commerce records, remotely sensed data and digital land use data including 50-100-years old topographic maps and a 25-years Landsat database.
- Build a database using a Geographic Information System (GIS) that incorporates geologic, geophysical and hydrologic history for medium and large-sized cities. The maps should focus on (i) mapping the aerial distribution of permeable strata and fracture zones and effects on the migration of ground and surface water, and on pollution plumes in these waters; (ii) mapping, geophysical surveys and hydrologic studies of hazards, such as expansive soils, flooding, subsidence due to groundwater withdrawal, landslides and faulting; (iii) provide a GIS-based information database that could be used for planning and zoning and communication and outreach to the public; and (iv) evaluation of stratigraphic and structural setting of the ground beneath the city to determine groundwater availability, petroleum, building materials and mineral resource potential.
- Construct a GIS database of the locations of toxic environmental pollutants that have begun to affect surface and groundwater in both urban and rural areas in the country. The contaminants which should be investigated include mercury, lead, arsenic, cadmium and selenium, among others. Wildlife and people are seriously affected by mercury-containing emissions from human-related activities.
- Geological Surveys should also assess and monitor the natural impact of rock type on both physical and chemical parameters of ecosystems (Clark, 2001). "Chemical parameters of ecosystems are affected by lithology because geologic materials and processes control initial availability of nutrients, acidity and oxidation-reduction potential, and metal contents of soils and water" (Clark, 2001).
- Geological Surveys should organize 'geosecurity seminars' which bring together key players in the planning and development of the urban centre. Each agency participant should be given a chance to discuss their major security concerns that relate to the urban physical environment.

I. Conclusions

The Geological Surveys of the region have made excellent progress in processing and communicating the pertinent urban geologic data to decision makers, especially in Central Asia. The geodata that should be used to guide the growth and development of cities in South, South-West and Central Asia are available in the files of the Geological Surveys throughout the region, but, at present, the potential for using that data is rarely being realized. Most of the Geological Surveys recognize that their traditional role of providing geologic data for engineering and planning purposes is becoming more important. Most of the Geological Surveys do not know how to cope with the impact of changing world economic conditions on their operations lamenting the fact that their budgets are reduced every year. They do not yet recognize the changes in market dynamics that will force them to become active seekers of clients and users of their data in order to maintain their existence in a giant wave of globalization.

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