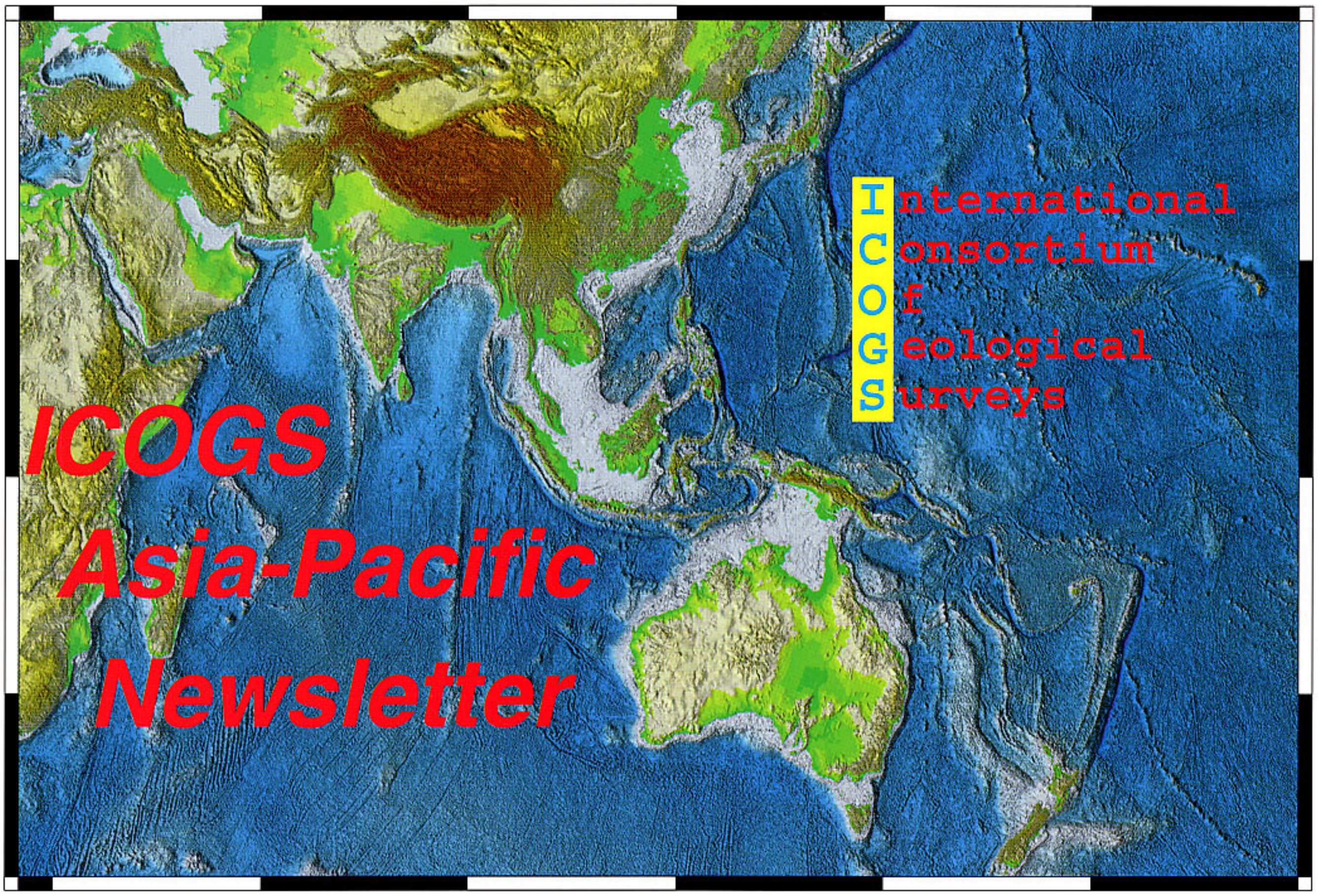

ICOGS ASIA-PACIFIC NEWSLETTER

No.6, March 2004

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From ICOGS Secretary for Asia and the Pacific

It is my great pleasure to send you the sixth issue of the ICOGS Asia-Pacific Newsletter after a delay of about a half year. I would like to express sincere appreciation to the contributors to this issue.

Mr. Chao-Chung Lin, Director, Central Geological Survey, Taiwan, submitted an article to the newsletter introducing their organization. As was described in his article, the island of Taiwan is located on the convergent boundary between two plates, and recent activities of the Central Geological Survey include geological hazards investigation, such as active faults and earthquake geology studies.

A report on recent restructuring of the Thai Government was submitted by the Department of Mineral Resources. The former Department of Mineral Resources was divided into four departments: the Department of Mineral Resources and the Department of Groundwater Resources under a new ministry, the Ministry of Natural Resources and Environment, the Department of Primary Industries and Mines under the Ministry of Industry, and the Department of Mineral Fuels under the Ministry of Energy. This reorganization probably reflects a global trend that sustainable development of natural resources and environmental protection are becoming increasingly important. It is interesting that the Department of Geology and Minerals of Vietnam also moved to the newly established Ministry of Natural Resources and Environment in January 2003.

Dr. Elena A. Konstantinovskaya submitted to the newsletter again a fine paper titled “Collision and extension at continental margins: examples of the Sea of Okhotsk”. This paper deals with the crustal structure and extensional tectonics of the Sea of Okhotsk, which is one of the most perspective areas in Russian Far East for oil and gas.

I also wrote an article to introduce a publication by the Geological Survey of Japan, AIST: Geological Map of East Asia, 1:3,000,000, which was recently compiled by my colleagues, Y. Teraoka and K. Okumura.

I would like to continue publishing the newsletter regularly. Any kind of information which may be of interest to other geological survey organizations will be accepted as an article for future issues of the newsletter. Short articles such as news on recently published maps and other publications would be fine. I particularly welcome information such as new trends in your country and organization. All correspondence relating to the ICOGS Asia-Pacific including its newsletter should be addressed to Takemi Ishihara.

Finally, I would like to express my sincere thanks to Dr. Yoshihiko Shimazaki for reading and editing all the manuscripts, and also to Mrs. Sumiko Miyano and Mrs. Akane Shima for their fine editorial work.

Takemi Ishihara
ICOGS Secretary for Asia and the Pacific
Geological Survey of Japan, AIST

THE CENTRAL GEOLOGICAL SURVEY, TAIWAN

Chau-Chung Lin

Director, Central Geological Survey, Taiwan

Main building of the Central Geological Survey.

INTRODUCTION

The Central Geological Survey (CGS) is a government agency responsible for geological survey and geosciences research. The fundamental work includes geologic survey, research, and compilation of geological map sheets that provide basic geological information. The Survey is also involved in investigations of environmental geology, hydrogeology, geological hazards, active faults, landslides, engineering geology, and mineral resources that are important to underpin the national economic and urban development and major construction projects.

The Survey was founded on November 20, 1978 to enhance the functioning of a national geological survey.

CGS has recognized capabilities in a wide range of geoscientific disciplines, notably multi-disciplinary geoscientific mapping and the preparation of high quality geoscientific maps. With a staff of 70 (plus approximately 40 temporary employees) and an annual budget of NTD 400 million (US$ 11 million), CGS's programs are implemented under the leadership of the Director and Deputy Director functions through six technical units: Planning Division, Regional Geology Division, Active Tectonics Division, Environmental & Engineering Geology Division, Geological Resources Division, and Geological Information Division. The Secretarial Office, Accounting Office, Personnel Office, and Governmental Ethics Office provide administrative support.

All of the research work is supported by laboratories well equipped with high precision instruments.

In south-central Taiwan, the collision between the Luzon volcanic arc and the Chinese continental margin has caused intense crustal thickening and shortening in the rising mountain range. In northeastern Taiwan, however, the northward subduction of the Philippine Sea plate beneath the Eurasian Plate has brought about arc volcanism and back-arc extension in the collapsing mountain ranges (Fig. 1). These mountain building and collapsing processes are very much alive and can be well illustrated by the rugged topography, rapid uplift and denudation, young tectonic landforms, active faulting, and numerous earthquakes (Fig. 2).

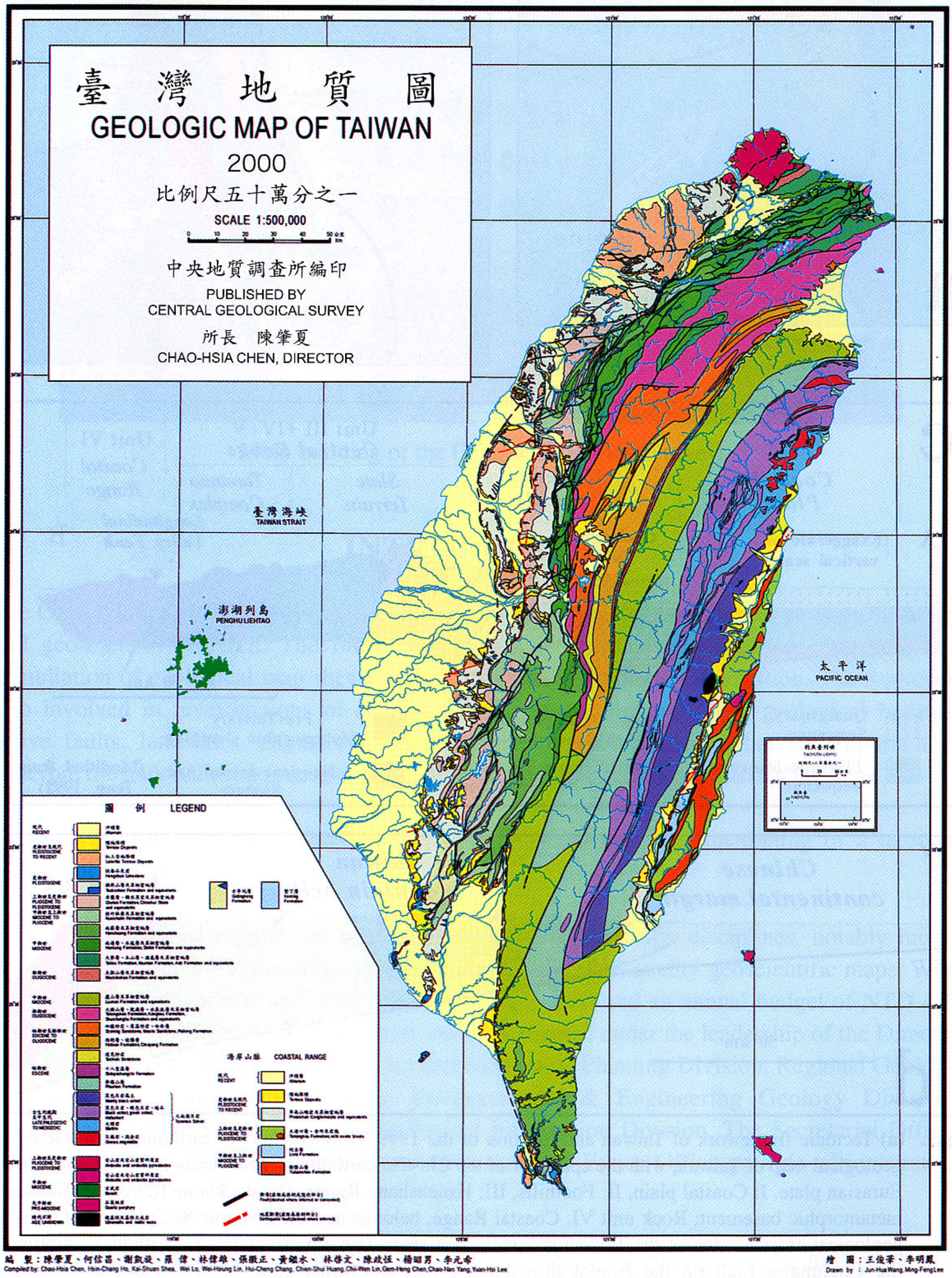

Fig.2. The Geologic Map of Taiwan.

Mapping of Surface Ruptures of the 1999 Chi-Chi Earthquake, Taiwan

Four years ago, a severe earthquake (Mw = 7.6) struck west-central Taiwan on September 21, 1999 (Fig. 1). It was the most destructive earthquake of the last century in Taiwan, killing about 2400 people and losing about 12 billion US dollars. An approximately 100-km surface rupture has become notorious for its savage destructiveness. Surface ruptures of co-seismic fault scarps and fold scarps with as much as 5-8 meters vertical throws and horizontal heaves are well exhibited through most the segments of the Chi-Chi earthquake fault (Fig. 3). Within two months, CGS has immediately produced a scale of 1: 25,000 Surface Rupture Map and a special volume on the investigation of the Chi-Chi Earthquake. More detailed surface rupture map with the cooperation of other organizations on a scale of 1: 5,000 is ready for the public within six months.

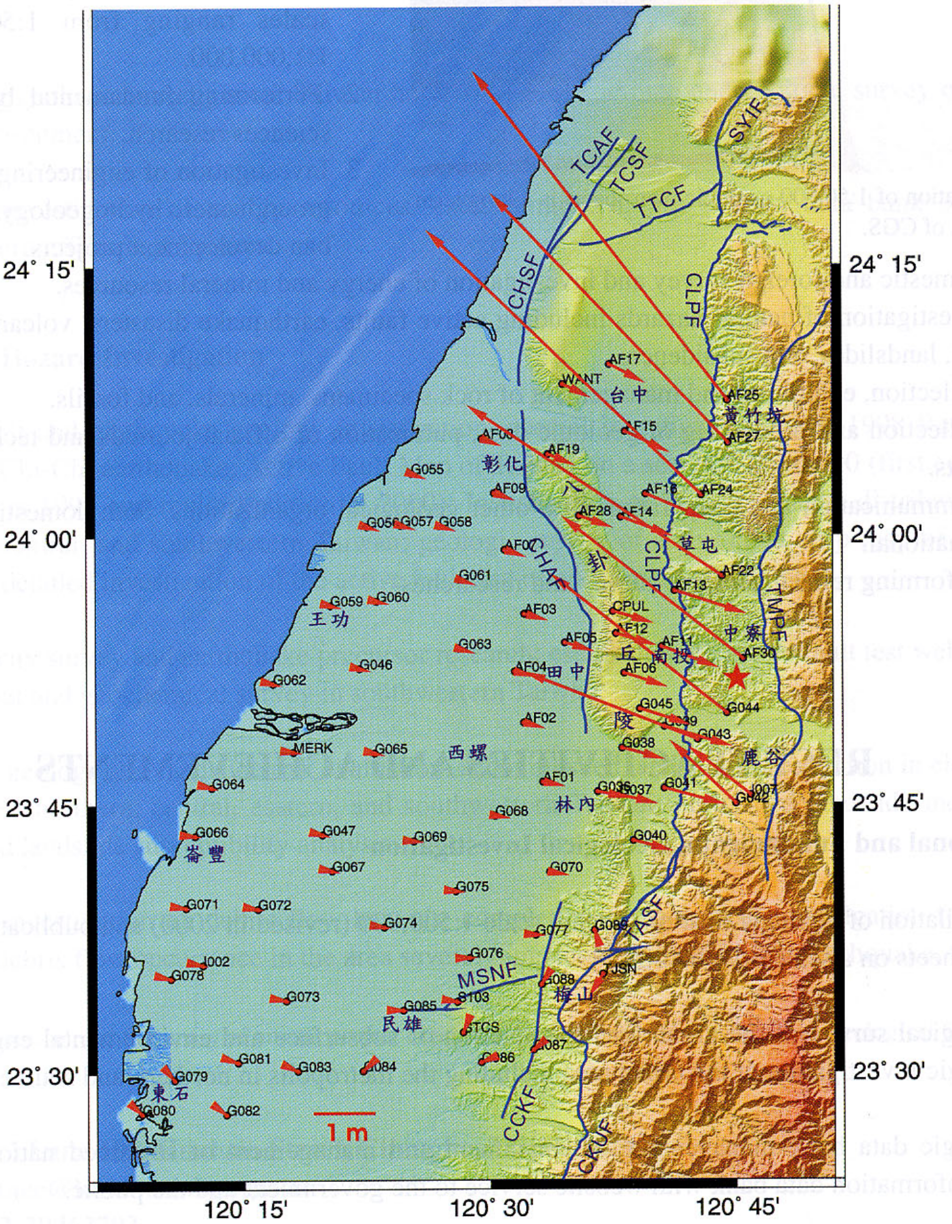

Fig.3. Horizontal displacements of Changhua fault and Chelungpu fault, Central Taiwan, based on GPS measurements from Feb. 1998 to Jan.2000.
TCAF, Tachia fault; TCSF, Tiechanshan fault; TTCF, Tuntzuchiao fault; CHSF, Chingshui fault; CHAF, Changhua fault; CLPF, Chenlungpu fault; TMPF, Tamaopu-Shuangtung fault; MSNF, Meishan fault; CCKF, Chiuchiugkeng fault; TASF, Tachienshan fault; CKUF, Chukou fault.

RESPONSIBILITY AND PERFORMANCE

Publication of 1:50,000 geologic map sheets is a long term project of CGS.

The Central Geological Survey, which aims to provide important basic geosciences information and lends support to the nation's economic development and major construction projects, performs the following duties:

1. Compilation of geologic map sheets for the whole territory of Taiwan on scales ranging from 1:50,000 to 1:1,000,000.
2. Performing fundamental basic geosciences research.
3. Investigation of engineering geology, groundwater, hydrogeology, and urban development projects.
4. Domestic and foreign survey and investigation of energy and mineral resources.
5. Investigation of natural hazards including active faults, earthquake disasters, volcanic activities, landslides, and subsidence.
6. Collection, exhibition and management of rock specimens, minerals, and fossils.
7. Collection and processing of geologic data; publication of official journals and technical reports.
8. Communication and cooperation with other geological organizations, both domestic and international.
9. Performing related geologic survey and researches.

RECENT ACTIVITIES AND ACHIEVEMENTS

Regional and Fundamental Geological Investigation

Compilation of geologic map of Taiwan: scale 1:500,000 (revised in 2000) and publication of 47 map sheets on a scale of 1: 50,000.

Geological survey of the urban area: completion of subsurface and environmental engineering geologic investigation of the urban area including the metropolis in northern and southern.

Geologic data bank management: establishment and management of sustained national-wide land information data bank with website service to the government and the public.

Data bank establishment with integrated geologic information on slopelands of the peripheries of major metropolis: integrated and supplementary environmental geologic survey of the metropolis and the adjacent area, compilation of environmental geologic map on a scale of 1: 25,000; establishment of environmental geologic and geologic hazard data bank.

Geologic Resources Investigation

Investigation of construction aggregate resources: investigation of sand and gravel resources on land, offshore area, and source rock of the lightweight aggregates.

Mineral resources investigation: geologic prospecting of metallic deposits in the northern and north-eastern Taiwan; publication of economic minerals of Taiwan (in three volumes including metallic, non-metallic, and energy resources and ground water); investigation of the source rocks of aggregates in the Hseuhshan Range.

Subsurface hydrogeology investigation: borehole drilling and monitoring the ground water of the alluvium fan of western Taiwan, and to establish the regional subsurface hydrogeology framework.

Hot spring geologic investigation: Taiwan hot spring geologic map and geologic survey of hot spring environment.

Geologic investigation of energy resources: establishment of gas hydrate data bank of the southwestern offshore of Taiwan.

Geologic Hazard Investigation

Active fault and earthquake geology investigation: special investigation of the 1998 Ruey-Li and 1999 Chi-Chi earthquake; Active Fault Map of Taiwan on a scale of 1:500,000 (first edition published in 1998 and revised edition in 2000); Investigation of 30 active faults distributed in northern, central, and southwestern Taiwan; geologic survey of active fault strip map of scale 1:25,000; detailed investigation of the active fault and establishment of data bank.

Fault activity survey and earthquake precursor research: establish three active fault test wells for geophysical and geochemical survey in southwestern Taiwan.

Landslide geology and landslide risk evaluation: accomplished landslide investigation in eleven Counties of northern, central, eastern, and southwestern Taiwan; performed landslide induced factors and landslide susceptibility analysis.

Geologic investigation on debris flow hazards: completion of geological investigation for the potential debris flow occurrence in the area severely impacted by the Chi-Chi Earthquake.

(for details please read Summary of annual project execution 2003 published by the Central Geological Survey, Taiwan)

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DEPARTMENT OF MINERAL RESOURCES OF THAILAND

Department of Mineral Resources
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BACKGROUND

The predecessor organization of the present DMR, was established on January 1, 1891 by King Chulalongkorn the great (Rama V) under the name of the "Royal Department of Mines and Geology". The Department was first involved with granting of tin mine concessions reporting to the Ministry of Agriculture. In the very early phase of the Department, its main duties consisted of development and exploitation of the country's mineral resources.

Since its establishment, the department went through nine periods of changes under the administration of five ministries. In 1933 her name was changed to the Royal Department of Mines.

In 1942 the Department of Mines became a department under the Ministry of Industry. The department was later transferred to the Ministry of National Development in 1965 under the current name of the "Department of Mineral Resources". The DMR was again under the Ministry of Industry after the Ministry of National Development was dissolved in 1972.

During the period between 1973 and 2002 when the DMR was attached to the Ministry of Industry, her responsibilities and scope of services expanded to cover all major fields related to mineral resources development, including petroleum and groundwater. The department expanded and extended her services by setting up 16 major divisions, 3 regional offices and 26 provincial offices.

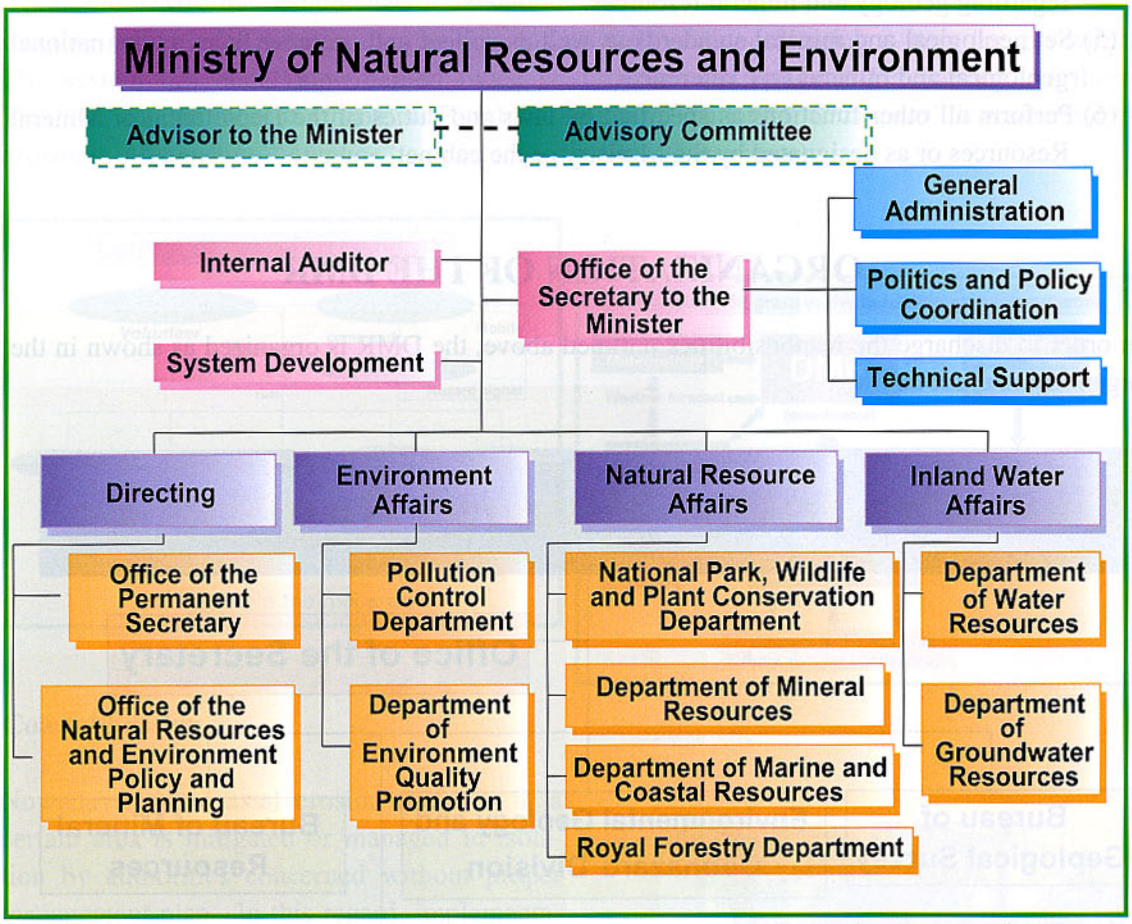
In accordance with the restructuring of the government organization of Thailand, the old Department of Mineral Resources under the Ministry of Industry was divided into the following four departments on 3 October 2002.

1. The Department of Mineral Resources under the Ministry of Natural Resources and Environment responsible for administration of geology and mineral resources.
2. The Department of Groundwater Resources under the Ministry of Natural Resources and Environment responsible for all issues regarding groundwater.
3. The Department of Primary Industries and Mines under the Ministry of Industry responsible for all issues regarding mining.
4. The Department of Mineral Fuels under the Ministry of Energy responsible for all issues regarding mineral fuels.

MISSION OF THE MONRE

The Ministry of Natural Resources and Environment (MONRE), newly established in October 2002, has a mission to "preserve, conserve, develop and rehabilitate natural resources and the environment to ensure their sustainable use, with active participation and support of the public and all stakeholders." In order to accomplish this mission, the ministry has adopted the following strategies:

1) Preserve, protect, conserve, use and rehabilitate the natural environment and biological diversity through public participation.
2) Supervise, monitor and rehabilitate the environment and mitigate pollution.
3) Support learning processes and people's access to natural resources based on equity.
4) Proactive and integrated administration.



MANDATE AND FUNCTIONS OF THE DMR

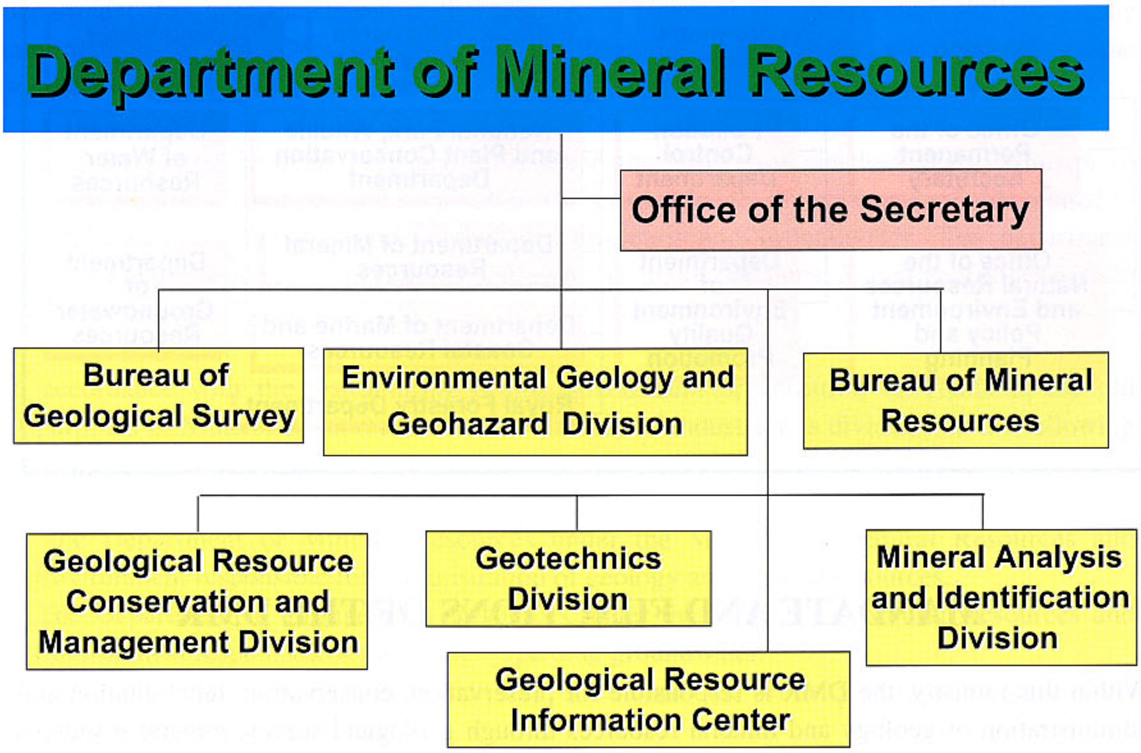
Within this ministry, the DMR is responsible for preservation, conservation, rehabilitation and administration of geology and mineral resources through geological survey, mineral resources investigation and evaluation, designation and supervision of the mineral resources preserved and conserved areas; for sustainable development of mineral resources, quality of life, economy and society.

The basic philosophy of the DMR is to "wisely use the geological resources with integrated management and public participation, as a firm foundation for national economic and social development". The Department is charged with implementing the following functions;

(1) Recommend areas, policies and plans for preservation, conservation, rehabilitation and administration of geology and mineral resources.
(2) Enforce in the related mineral act in compliance with related laws and regulations.
(3) Recommend amendments and rectification of laws, regulations and measures concerning preservation, conservation, rehabilitation and administration of geology and mineral resources. As well as supervise and monitor compliance of laws, regulations and measures.
(4) Carry out surveys, inspection, studies, researches, develop knowledge base concerning mineral resources, disseminate information and knowledge concerning mineral resources, provide technical services, cooperate with foreign and international organizations regarding geology and mineral resources.
(5) Set geological and mineral standards as well as collect and preserve them as the national geological and mineral type references.
(6) Perform all other functions as specified by laws and duties of the Department of Mineral Resources or as designated by the Ministry or the cabinet.

ORGANIZATION OF THE DMR

In order to discharge the responsibilities outlined above, the DMR is organized as shown in the organization chart below.

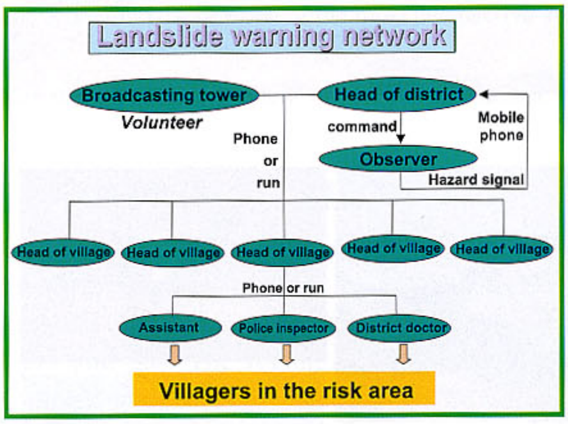


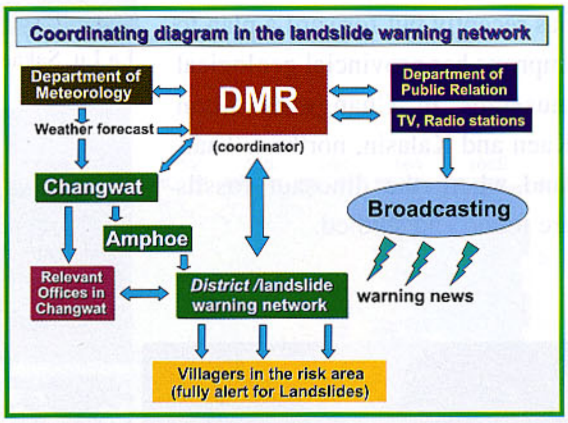
RECENT WORK

Mitigation of Public Vulnerability to Landslide Hazard

One of the important issues of the DMR is mitigation of public vulnerability to natural hazards. The landslide of Ban Nam Kor, Chanwat Petchaboon occurred on 11 August 2001, causing disastrous damage: 136 people were killed, 109 people were injured, and 215 houses were destroyed.

In order to mitigate public vulnerability of landslide hazards, apart from the technical work, the DMR has established a landslide warning network for people in high-risk areas, as well as a coordinating system for this work. The system has been implemented twice so far, one in Changwat Petchaboon, northern Thailand, and the other in Changwat Pattalung, southern Thailand (*"Changwat" is equivalent to province. Meanwhile, "Amphoe" can be compared as sub-province*).





Coastal Erosion

Nowadays, the coastal erosion problem in a certain area is mitigated or managed in isolation by authorities concerned without proper management plan. In this regard, implementation of certain measures to solve a particular area may generate negative impacts to the areas nearby and some certain areas further away. The government has recognized this significant problem and raised it as a national issue.

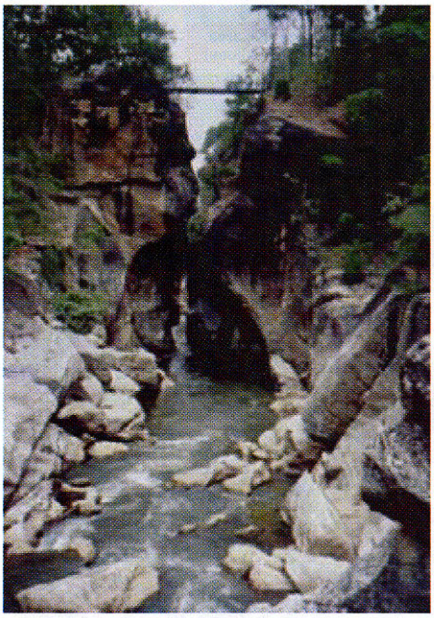

Changwat Satun, 6-7 meters/yr.

The government's policy is in the process of formulation focusing on integrated management, public participation, revision of laws, and research and development. Its goals target on solving the problem in the critical areas meanwhile preventing the sensitive areas from being eroded. Under this policy, a national committee composing of relevant organizations of ministerial level will be set up to take care of the management in the top level. Meanwhile, the Department of Mineral Resources and the Department of Marine and Coastal Resources, Ministry of Natural Resources and Environment will be the key organizations to drive the mechanism in the action level.

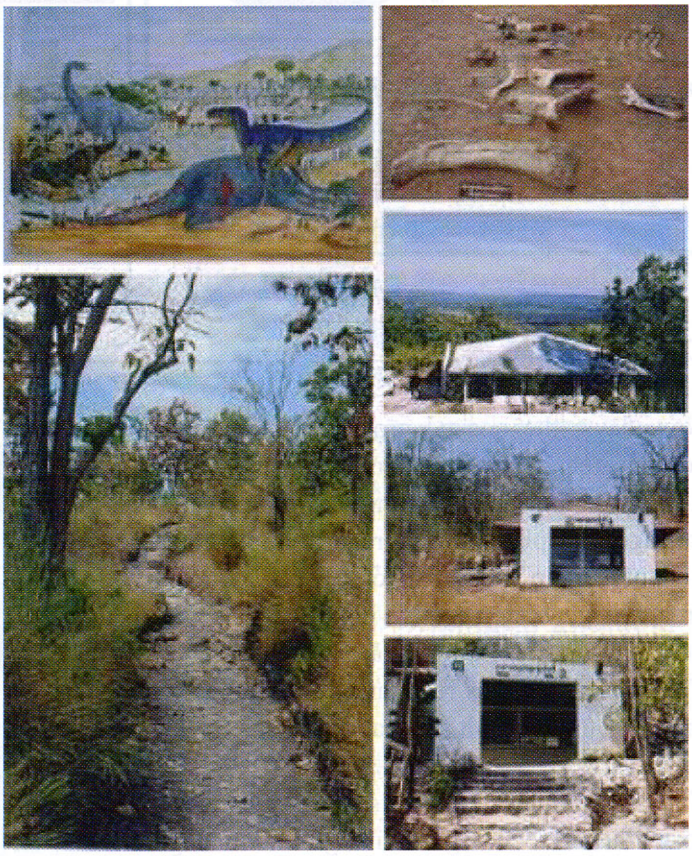
Increasing public awareness in geological resources

One of the ministerial strategies and DMR mandates is to disseminate geoscience information and knowledge to the public so as to increase the public understanding in geological phenomena and recognition of geological resource conservation, and to promote the use of geoscience knowledge and information to public and relevant organizations. The DMR has recently put forward a plan to improve her provincial geological museums in Changwats Khon Kaen and Kalasin, northern Thailand where the dinosaur fossils are found and studied.

La Lu, Sakaew



Ob Luang, Chiang Mai



Phu Wiang, Khon Khan

COLLISION AND EXTENSION AT CONTINENTAL MARGINS: EXAMPLE OF THE SEA OF OKHOTSK

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The crustal structure of the northern Sea of Okhotsk region was reworked after the relict Okhotsk Sea plate collided with Eurasia about 55 Ma. Post-collisional extension and magmatic processes were likely initiated within the Okhotsk Sea plate and Asian margin along the remnant convergent plate boundary. The crustal structural pattern differs from the north and from the south by the remnant plate boundary. To the north, a series of northeast trending normal faults started to form during the Eocene extension within the Asian margin after collision with the Okhotsk Sea plate. To the south, a series of southeast trending normal faults was initiated due to extension within the Okhotsk Sea plate during the latest Oligocene through Early Miocene. Formation of Eocene volcanic rocks likely marks the magmatic processes which occurred at the beginning of Tertiary extension in the Sea of Okhotsk. The region of the Sea of Okhotsk and Sakhalin Island is one of the most perspective areas for oil and gas in the Russian Far East.

Key words: collision, extension, tectonics, volcanic activity, fossil plate boundary, Sea of Okhotsk.

INTRODUCTION

Continental shelf of Russian Federation has an areal extent of more than 6 million km^2 and contains huge resources of petroleum and gas. The region of the Sea of Okhotsk and Sakhalin Island (Fig. 1) is one of the most perspective areas for oil and gas in the Russian Far East. Numerous geophysical studies have been carried out in the Sea of Okhotsk for exploration and development of hydrocarbons (Kropp, 2002).

More than 20 Cenozoic sedimentary basins are known in the Sea of Okhotsk. Tectonic evolution of the sedimentary basins is related to several stages of extension during the Cenozoic. Deformation of lithosphere and crustal tectonics during the Early Tertiary extension is likely determined by geodynamic behavior of the Okhotsk Sea plate and Asian plate along the remnant convergent plate boundary in the northern Sea of Okhotsk.

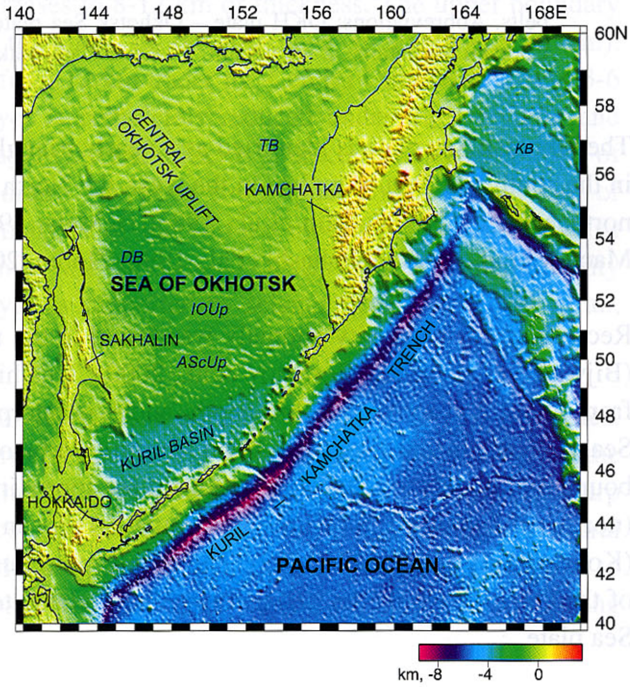

Fig.1. Geographic index map of the Sea of Okhotsk region. Abbreviations:*IOUp*–Institute of Oceanology uplift, *AScUp*–Academy of Sciences uplift, *DB*– Deryugin basin, *TB*–Tinro basin, *KB*– Komandorsky basin.

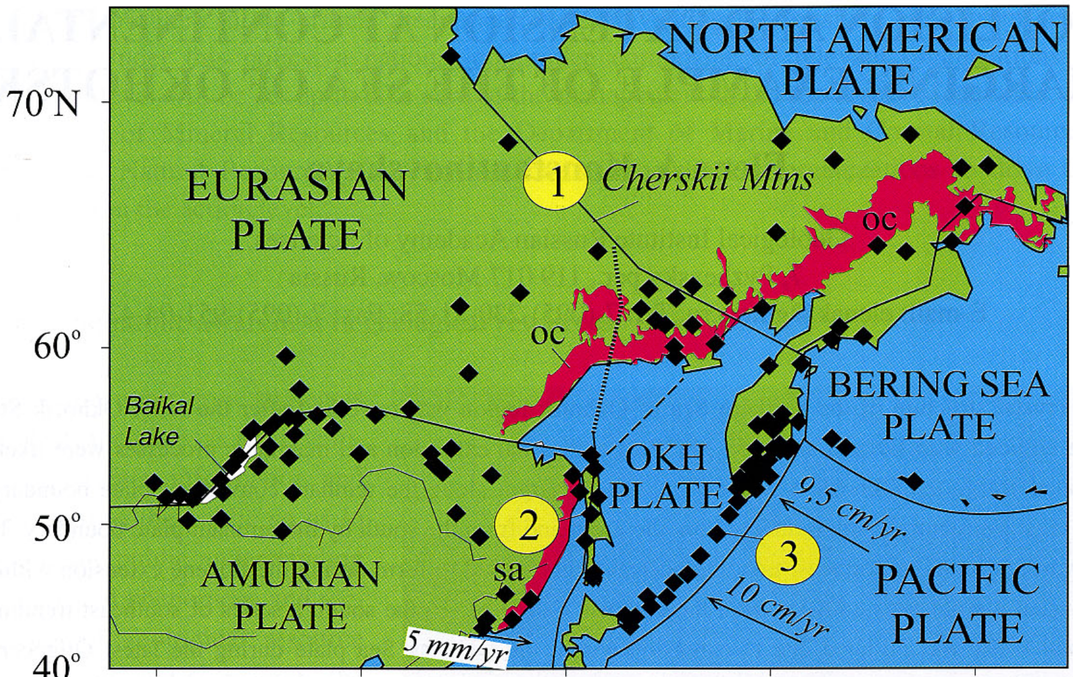

Fig.2. Geodynamic framework of the Okhotsk Sea plate.
Solid lines denote plate boundaries, after (DeMets, 1992; Seno, 1996; Mackey et al., 1997). Pointed and dashed lines indicate the Okhotsk-Eurasia plate boundary after GPS (DeMets, 1992) and tomography (Gorbatov et al., 2000) data, respectively. Arrows indicate the relative velocity vectors of the Pacific and Amurian plates with respect to Eurasia at different scales, after (Takahashi et al., 1999). Solid diamonds indicate the distribution of the seismic stations of the Geophysical Survey of Russia. Red shadows show the location of the Okhotsk-Chukotka (oc) and Sikhote-Alin (sa) volcanic-plutonic belts. Abbreviations: OKH plate – Okhotsk Sea plate. Numbers in circles indicate seismic belts: 1 – Cherskii Mountains, 2 – Sakhalin, 3 - Kuril-Kamchatka.

The Okhotsk Sea plate is identified as a nearly triangle-shape plate bordered by the Pacific plate in the south, the Amurian plate in the west, the North American and the Bering Sea plates in the northeast (Fig. 2) (Savostin et al., 1983; DeMets, 1992; Lander et al., 1996; Seno et al, 1996; Mackey et al., 1997; Takahashi et al., 1999; Zlobin, 2002).

Recently, a high velocity anomaly was found in the mantle under the northern Sea of Okhotsk (Bijwaard et al., 1998; Gorbatov et al., 2000). This high-velocity anomaly dips to the northwest from about 200 km to 600 km depth, and it is interpreted as a relict of the Mesozoic Okhotsk Sea plate subducted under the Asian margin (Gorbatov et al., 2000). The fossil convergent plate boundary laterally extends northeastward for approximately 800 km from the Schmidt Peninsula (northern Sakhalin) to Kony Peninsula (Asia) in the northern Sea of Okhotsk (Fig. 2) (Konstantinovskaya et al., 2003). The Late Cretaceous volcanic activity in the southern segment of the Okhotsk-Chukotka belt is most likely related to the subduction of the Mesozoic Okhotsk Sea plate.

CRUSTAL STRUCTURE OF THE NORTHERN SEA OF OKHOTSK

The average crustal thickness under the Central Okhotsk uplift is in the orders of 29-30 km, thinning under the Deryugin and Tinro basins to 22 km and 19 km, respectively.

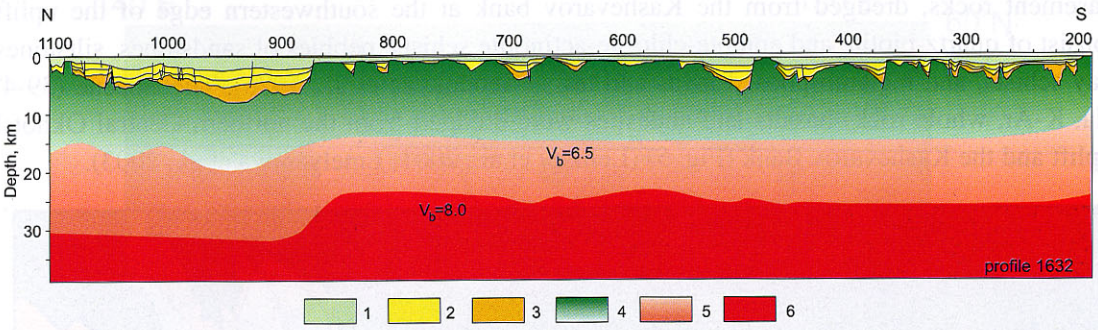

Fig.3. The CDP reflection seismic profile 1632, after (Ageev et al , 2002). Location of the profile is shown in Fig. 4.
1-3 – sedimentary layer (1 – Pliocene-Quaternary, 2 – Miocene, 3 – Oligocene-Lower Miocene seismic series); 4 – upper crustal layer; 5 – lower crustal layer; 6 – upper mantle. V_b - boundary velocities, km/s.

The consolidated crust of the Sea of Okhotsk is divided into the upper and lower crusts (Fig. 3) (Bogdanov and Khain, 2000):

Crustal Layer	Upper boundary velocities (km/s)	Layer velocities (km/s)	Density (g/cm^3)	Thickness (km)
Lower (3rd layer)	6.8-7.2	6.5-6.7	3.9 to 3.1	15-20
Upper (2nd layer)	6.0-6.4	5.0-6.4	2.8-3.2	0-3-6 to 12

Magnetic bodies are distinguished at the bottom of lower crustal layer, where they form a separate horizon of 4-6 km thick which increases to 8-12 km of thickness. The upper boundary of the lower crust is subhorizontal, and thickness of the 3rd layer is stable (15-20 km). Thickness of the upper crustal layer varies from 12 km under the Central Okhotsk Uplift to 3-6 km under sedimentary basins, and this layer is completely reduced under the Deryugin and Tinro troughs. The uppermost part of 2nd layer (2-3 km thick) is characterized by anisotropy of physical properties typical for fissured medium. Transition from upper crust to lower part of sedimentary layer is locally continuous. Analysis of the surface morphology of upper crust suggests that it is highly eroded (Bogdanov and Dobretsov, 2002). A sharp unconformity characterizes the bottom of sedimentary layer as supported by seismic profiling (Ageev et al., 2002).

The crustal structure of the northern Sea of Okhotsk is affected by active Tertiary tectonics. Trough and half graben systems, which surround the Central Okhotsk uplift, formed during the Cenozoic time (Worrall et al., 1996; Kharakhinov, 1996; Bogdanov and Khain, 2000). The sharp boundary at the base of the sedimentary column corresponds to the Early Tertiary structural unconformity. Large sedimentary basins at the periphery of the Okhotsk Sea plate correspond to the centers of maximum extension and subsidence with intense sediment accumulation during the Cenozoic (Fig. 4).

Within the Central Okhotsk uplift, the sedimentary cover is not deformed and is relatively thin (less than 1 km) (Fig. 5). The Middle Miocene – Quaternary strata non-conformably overlies the smooth surface of the basement with a sharp boundary (Kharakhinov, 1996). The northeast trending normal faults and grabens occur in the basement of the northern Central Okhotsk uplift (Fig. 5).

Basement rocks, dredged from the Kashevarov bank at the southwestern edge of the uplift, consist of quartz-biotite and epidote-chlorite-actinolite schists, pebbles of sandstones, siltstones, clay schists, and metamorphosed lavas and tuffs (Geodekyan et al., 1976). The Eocene (39-47 Ma, K-Ar, whole rock) basalts and andesites were dredged from the northern Central Okhotsk Uplift and the Kashevarov Bank (Fig. 5) (Lelikov et al., 2001; Emelyanova et al., 2003).

Fig.4. Main sedimentary basins of the Sea of Okhotsk, modified after (Salnikov, Kharakhinov, and Shainyan, 1996).

Grey and orange shadows show offshore sedimentary basins and the areas with relatively thin sedimentary cover, respectively. Abbreviations: *IOUp* – Institute of Oceanology uplift, *AScUp* – Academy of Sciences uplift. The numbers indicate the sedimentary basins: I – North Sakhalin, II – West Sakhalin, III – South Sakhalin, IV – West-Kamchatka, V – Shantar, VI – Kukhtuy, VII – Magadan, VIII – Gizhigin, IX – Tinro, X – Deryugin, XI – South Okhotsk, XII – Middle Kuril.

1 – oil field, 2 – gas field, 3 – offshore drilling area, 4 – parametric borehole: *M1* – Magadan N1, *Kh* – Khmitev.

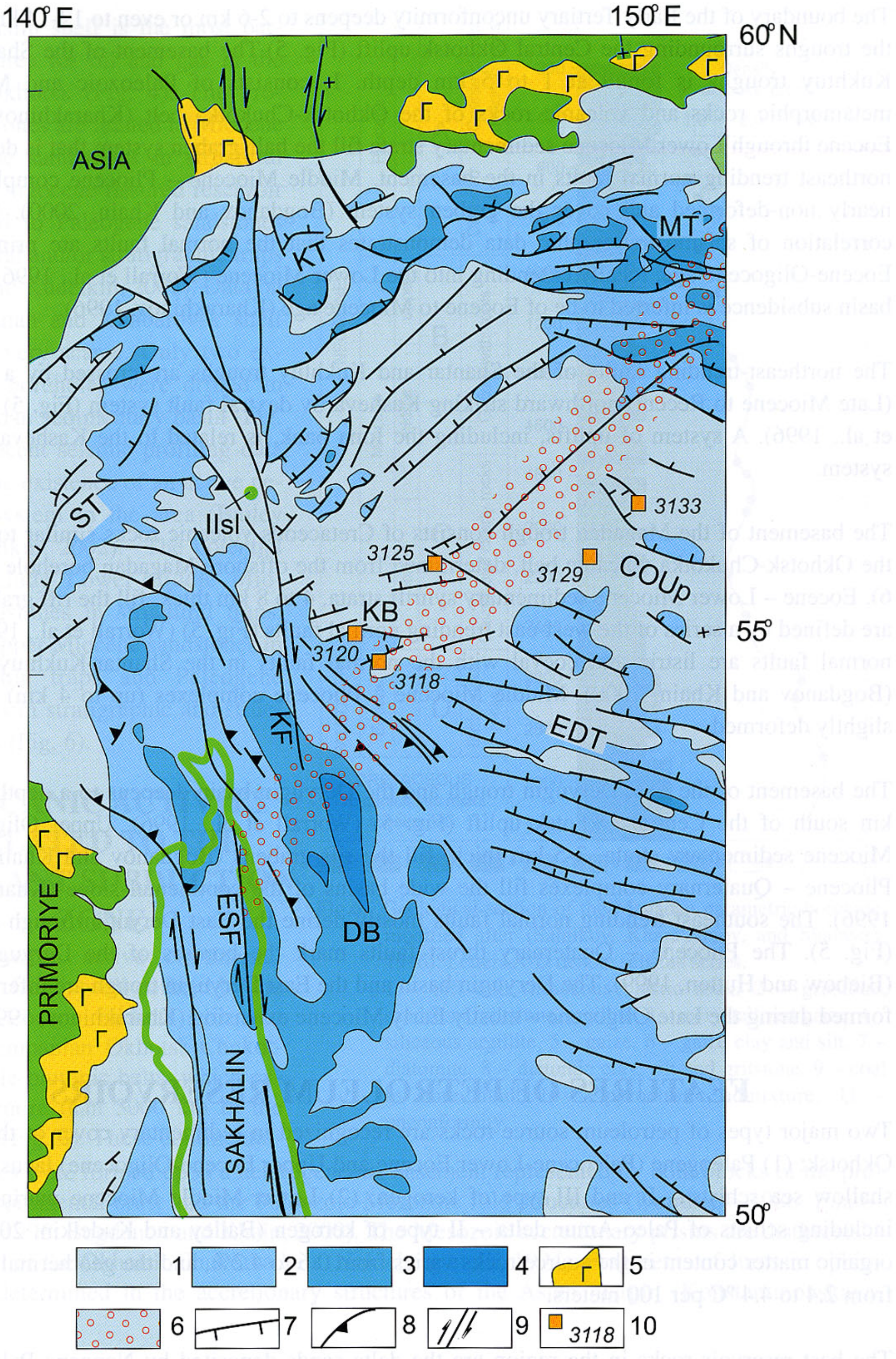

Fig.5. Structural map of the northern Sea of Okhotsk showing major Tertiary structural trends and depth to the Early Tertiary unconformity, compiled after reflection seismic data (Worrall et al., 1996; Kharakhinov, 1996; Biebow, and Hutten, 1999).

1-4 - the depth range to the Early Tertiary unconformity (1 – 0-2 km, 2 – 2-6 km, 3 – 6-10 km, 4 – 10-14 km); 5 – Eocene to Recent mafic volcanic rocks, 6 – location of the Okhotsk Sea remnant subduction zone; 7-9 - faults: 7 - normal, 8 – reverse, 9 - strike-slip; 10 – location of dredged samples of Eocene volcanic rocks. Abbreviations: ST – Shantar trough, KT – Kukhtuy trough, MT – Magadan trough, EDT – East Deryugin trough, DB – Deryugin basin, COUp – Central Okhotsk uplift, IIsl – Iona Island, KB – Kashevarov bank, KF – Kashevarov fault, ESF – East Sakhalin fault.

The boundary of the Early Tertiary unconformity deepens to 2-6 km or even to 12-14 km toward the troughs surrounding the Central Okhotsk uplift (Fig. 5).The basement of the Shantar and Kukhtuy troughs is found at 1 to 5 km depth. It consists of Paleozoic and Mesozoic metamorphic rocks and volcanic rocks of the Okhotsk-Chukotka belt (Kharakhinov, 1996). Eocene through Lower Miocene sedimentary strata fill the half-graben system that is defined by northeast trending normal faults in the basement. Middle Miocene – Pliocene complexes are nearly non-deformed and cover the graben system (Bogdanov and Khain, 2000). Regional correlation of seismostratigraphic data demonstrates that the normal faults are primarily of Eocene-Oligocene age, locally extending into the Lower Miocene (Worrall et al., 1996). Synrift basin subsidence is inferred to be of Eocene to Miocene age (Kharakhinov, 1996).

The northeast-trending faults of the Shantar and Kukhtuy troughs are crossed by a younger (Late Miocene to Recent) northward striking Kashevarov dextral fault system (Fig. 5) (Worrall et al., 1996). A system of uplifts, including the Iona bank, is related to the Kashevarov fault system.

The basement of the Magadan trough consists of Cretaceous volcanic rocks similar to units of the Okhotsk-Chukotka volcanic belt, determined from the offshore Magadan borehole N1 (Fig. 6). Eocene – Lower Miocene sedimentary synrift strata, 4 to 8 km thick, fill the rift grabens that are defined by a series of the west-east trending normal faults (Fig. 5) (Worrall et al., 1996). The normal faults are listric and coeval with the normal faults in the Shantar-Kukhtuy troughs (Bogdanov and Khain, 2000). Middle Miocene – Pliocene complexes (up to 4 km) are very slightly deformed.

The basement of the East Deryugin trough and the Deryugin basin deepens to a depth of 6-12 km south of the Central Okhotsk uplift (Fig. 5) (Worrall et al., 1996). Upper Oligocene – Miocene sedimentary strata, 3-5 km thick, fill the rift grabens (Bogdanov and Khain, 2000). Pliocene – Quaternary complexes fill the wide basins of the continental slope (Kharakhinov, 1996). The southeast trending normal faults mostly define the East Deryugin trough structure (Fig. 5). The Pliocene – Quaternary thrust faults mark the borders of the Deryugin basin (Biebow and Hutten, 1999). The Deryugin basin and the East Deryugin trough are inferred to be formed during the Late Oligocene – mostly Early Miocene extension (Kharakhinov, 1996).

FEATURES OF PETROLEUM RESERVOIRS

Two major types of petroleum source rocks are recognized in sedimentary cover of the Sea of Okhotsk: (1) Paleogene (Paleocene-Lower Eocene and Upper Eocene-Oligocene) lacustrine and shallow sea schists – II and III type of kerogen; (2) Lower-Middle Miocene marine schists including schists of Paleo-Amur delta – II type of kerogen (Bailey and Kudelkin, 2002). The organic matter content in the source rocks varies from 0.6 to 4.2%, and the geothermal gradient from 2.4 to 4.4 °C per 100 meters.

The best reservoir rocks in the region are the delta sands deposited by Neogene Paleo-Amur system (Fig. 4). The gas flux in these rocks reached up to 160 million ft^3 per day and the oil flux – up to 12 thousand barrels per day during the test (Bailey and Kudelkin, 2002). The sand beds vary from several tens of meters to 100 m in thickness and are characterized by excellent reservoir quality with high permeability and porosity exceeding 20 %. Oligocene siliceous argillites are recognized as a potential reservoir in the Southern Sakhalin offshore basins. The thick beds of Paleogene alluvial sandstones likely represent the best reservoir rocks in the Magadan and West-Kamchatka sedimentary basins.

The Sakhalin shelf is the most perspective area for oil and gas in the Sea of Okhotsk (Fig. 4). The prospecting zones are related to Miocene – Pliocene sandstones in structural traps, to Oligocene fissured reservoir rocks, and to Paleogene sandstones in structural and/or stratigraphic traps (Bailey and Kudelkin, 2002). Data on the Magadan and Khabarovsk shelf areas are very scarce. Only two exploratory boreholes were drilled in the Magadan sedimentary basin (Fig. 4). The recent seismic profiling data suggest the existence of an active petroleum system in the area (Bailey and Kudelkin, 2002). The potential zones include Lower-Middle Miocene sandstones in structural traps, Middle-Upper Miocene sandstones in stratigraphic traps and Paleogene sandstones in stratigraphic and structural traps (Fig. 6).

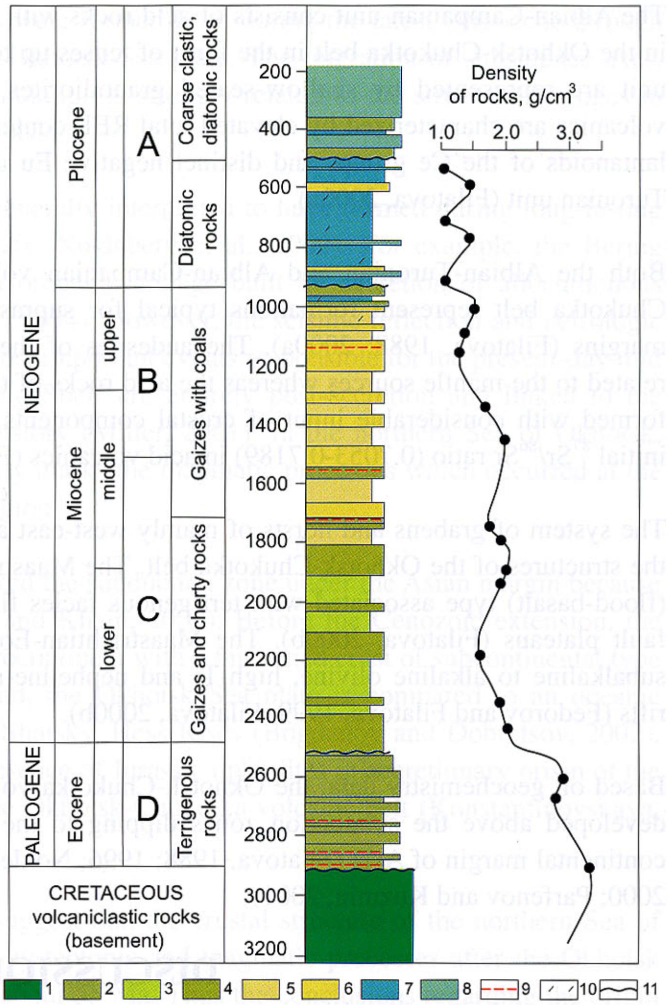

Fig.6. Geological section of the Magadan parametric borehole, modified after (Salnikov, Kharakhinov, and Shainyan, 1996). Letters A-D denote seismic series.

1 – tuff and tiffaceous clastic rock, 2 – gritstone, sandstone, siltstone, argillite, 3 – recrystallized gaize, 4 – siliceous argillite, 5 – gaize, 6 – gaize clay and silt, 7 – diatomite, 8 – diatomic clay, silt and gritstone, 9 – coal in bore mud, 10 – pyroclastic admixture, 11 – unconformity.

VOLCANIC ACTIVITY RELATED TO THE REMNANT SUBDUCTION ZONE

The Mesozoic active continental margin of Asia is well defined by the Senonian-Eocene Sikhote-Alin and Albian-Campanian Okhotsk-Chukotka volcanic-plutonic belts, which extend for more than 3000 km to the northeast (Fig. 2). These continental-margin arcs were formed upon a heterogeneous basement represented by both blocks of the pre-Riphean continental crust and the Paleozoic-Mesozoic fold structures (Umitbaev, 1986; Filatova, 1988; 1996; Bogdanov and Khain, 2000). The Mesozoic accretionary prisms are distinguished in front of the Okhotsk-Chukotka belt (Nokleberg et al., 1994). Fragments of Jurassic ophiolites are determined in the accretionary structures of the Asian margin (Konstantinovskaya, 1998).

The Okhotsk-Chukotka volcanic-plutonic belt includes the Albian-Turonian andesite unit and the Albian-Campanian acid rock unit (Filatova, 2000a). The Albian-Turonian unit consists of lavas and tuffs of andesites, basaltic andesites and about 10% of rhyolites and dacites. Thickness of the unit ranges from 800 to 2000 m. Intrusive rocks include diorites, granodiorites and granites. The Albian-Turonian volcanic rocks are characterized by high Al content, lower Ti, Mg, Fe. Li, Co and V contents, enriched Sr and Zr contents, and show fractionated distribution of the rare earth elements (REE) with enrichment in light lantanoids, similar to calc-alkaline volcanics from the Andean belt (Filatova, 2000a).

The Albian-Campanian unit consists of acid rocks with predominant ignimbrites, which spread in the Okhotsk-Chukotka belt in the form of lenses up to 1.5-2 km thick. Intrusive rocks of the unit are represented by shallow-seated granodiorites and granites. The Albian-Campanian volcanics are characterized by elevated total REE contents with highest fractionation degree of lantanoids of the Ce groups and distinct negative Eu anomaly as compared with the Albian-Turonian unit (Filatova, 2000a).

Both the Albian-Turonian and Albian-Campanian volcanic-plutonic units of the Okhotsk-Chukotka belt represent formations typical for suprasubduction zones of active continental margins (Filatova, 1988; 2000a). The andesites of the Albian-Turonian unit are most likely related to the mantle sources whereas the acid rocks of the Albian-Campanian unit are probably formed with considerable input of crustal components as suggested from high values of the initial $^{87}Sr/^{86}Sr$ ratio (0.7053-0.7189) in acid volcanics (Filatova, 2000a).

The system of grabens and horsts of mainly west-east and southwest-northeast strikes disturbs the structures of the Okhotsk-Chukotka belt. The Maastrichtian-Eocene basalts of the intraplate (flood-basalt) type associated with terrigenous facies fill the grabens and form spacious near-fault plateaus (Filatova, 2000b). The Maastrichtian-Eocene basaltoids include varieties from subalkaline to alkaline olivine, high-Ti and nepheline-normative rocks, typical of continental rifts (Fedorov and Filatova, 1999; Filatova, 2000b).

Based on geochemistry data, the Okhotsk-Chukotka volcanic-plutonic belt is assumed to have developed above the subduction zones dipping to the northwest under the Mesozoic active continental margin of Asia (Filatova, 1988; 1996; Nokleberg et al., 2000; Bogdanov and Khain, 2000; Parfenov and Kuzmin, 2001).

DISCUSSION

The remnant subduction zone in the northern Sea of Okhotsk extends northeastward for a distance of about 800 km which is similar to some subduction zones in the South-East Asia, such as along the Philippine trough. The Okhotsk Sea remnant slab was likely subducted under the Mesozoic active margin of Asia producing the Cretaceous volcanic activity in the southern segment of the Okhotsk-Chukotka belt. The magmatic activity in the belt ceased when the Okhotsk Sea plate collided with Asia around 55 Ma.

The present distance from the onshore Cretaceous volcanic rocks of the Okhotsk-Chukotka belt to the Okhotsk Sea remnant subduction zone is about 300-350 km (Fig. 5). This value is very high when compared to recent suprasubduction continental-margin arcs. However, Cretaceous volcanic rocks, typical to the belt units, occur also offshore, in the basement of the Shantar, Kukhtuy and Magadan troughs as supported from seismostratigraphic studies and data from the offshore Magadan borehole N1 (Fig. 6). If so, the distance from the volcanic front of the Okhotsk-Chukotka belt to the subduction zone is about 100-150 km. The Cenozoic extension that affected the crustal structures of the northern Sea of Okhotsk since the Eocene may also contribute to the distance growth between the volcanic front and the remnant subduction zone.

The Okhotsk-Asia remnant plate boundary separates the crustal blocks of different ages and structural patterns (Fig. 5). To the north, a series of northeast trending normal faults, grabens and rifting structures occur in the upper crust running parallel to the Okhotsk Sea remnant subduction zone. These structures started to form during the Eocene extension, which was likely initiated at the Asian margin after collision with the Okhotsk Sea plate. To the south of the remnant subduction zone, a series of the southeast trending normal faults and grabens affects the upper crust. These structures were formed later, during the latest Oligocene through Early Miocene due to extension in the Okhotsk Sea plate. The migration of subsidence axes, fluids, and zones of hydrocarbon accumulation is strongly related to the structural changes in the sedimentary cover of the Sea of Okhotsk.

Pacific active continental margins are generally interpreted to have formed during long-lasting tectonic accretion of far-traveled terranes (Nokleberg et al., 2000). For example, the Bering Shelf was previously interpreted as an orogenic collage built by accretion of allochthonous terranes in Cretaceous (Nokleberg et al., 1994). However, the seismic reflection and petrologic data from this region indicate that the most important events responsible for the present-day mid and lower crust formation of the Bering Shelf are entirely post-accretion and linked to the regional magmatic, non accretionary, history (Miller, 2001). In the northern Sea of Okhotsk, formation of Eocene volcanic rocks likely marks the magmatic processes which occurred at the beginning of Tertiary extension in the region.

The Okhotsk Sea plate most likely blocked the subduction zone under the Asian margin because of its relatively thick crust (Bogdanov and Khain, 2000). Before the Cenozoic extension, the plate is suggested to be similar to a microcontinent with a thickened crust of subcontinental type (Kharakhinov, 1996). On the other hand, the Okhotsk Sea plate is compared to an oceanic volcanic plateau like the Ontong-Java, Shatsky, Hess Rises (Bogdanov and Dobretsov, 2002). The latter hypothesis is supported by presence of Jurassic ophiolites in accretionary prism of the Mesozoic Asian boundary in front of the Okhotsk-Chukotka volcanic belt (Konstantinovskaya, 1998).

Data present in this paper allow us to suggest that the crustal structure of the northern Sea of Okhotsk region was strongly reworked by tectonic and magmatic processes after the Okhotsk Sea plate collided with Asian continent about 55 Ma. Thus the conclusions regarding the origin of the plate should be taken with precaution if based directly on analysis of the present crustal structure.

CONCLUSIONS

The crustal structure of the northern Sea of Okhotsk region was reworked after the relict Okhotsk Sea plate collided with Eurasia about 55 Ma. Post-collisional extension and magmatic processes were likely initiated within the Okhotsk Sea plate and Asian margin along the remnant convergent plate boundary. The crustal structural pattern differs from the north and from the south by the remnant plate boundary. To the north, a series of northeast trending normal faults started to form during the Eocene extension within the Asian margin after collision with the Okhotsk Sea plate. To the south, a series of southeast trending normal faults was initiated due to extension within the Okhotsk Sea plate during the Latest Oligocene through the Early Miocene. Formation of Eocene volcanic rocks likely marks the magmatic processes which occurred at the beginning of Tertiary extension in the Sea of Okhotsk.

FURTHER STUDIES

The following objectives still stay unexplored in the Sea of Okhotsk:

(1) Identification and analysis of the morphologic and structural elements related to the remnant Asia-Okhotsk convergent plate boundary.

(2) Comprehensive study of extensional mechanism developed in the Okhotsk Sea plate and Asia after collision about 55 Ma. Geodynamic analysis of the evolution of sedimentary basins in the north of the Sea of Okhotsk.

(3) Study of Paleocene volcanic rocks formed at the beginning of extension in the region of remnant plate boundary.

(4) Evaluation of the earthquake potential and crustal movement along the remnant plate boundary. For instance, the area of active gas field exploitation around of Okha city is located at the southwestern edge of the Okhotsk Sea remnant slab.

(5) Contouring of lateral extent of continental crust in the Sea of Okhotsk drilling programs can significantly improve our understanding of processes occurring in this area.

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PUBLICATION OF GEOLOGICAL MAP OF EAST ASIA, 1:3,000,000

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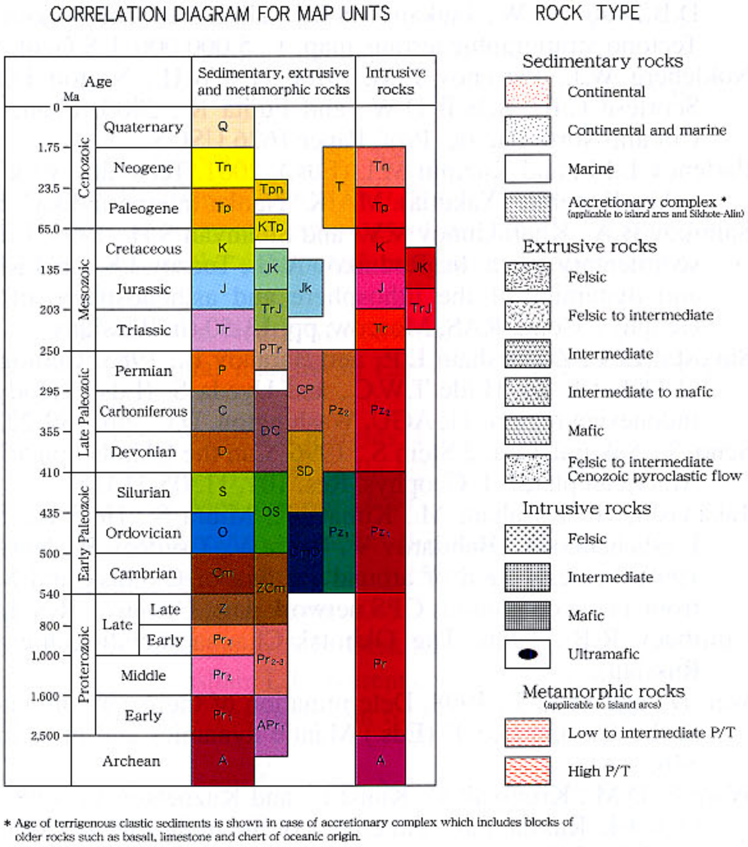
Geological Map of East Asia, 1:3,000,000 was recently compiled by Teraoka and Okumura (2003) and published by Geological Survey of Japan (see the back cover for a reduced map of the whole area).

The map covers about 2/3 of China, eastern half of Mongolia, whole of the Korean Peninsula, Japan and Taiwan. It also includes parts of Far East Russia, Vietnam, Laos and Myanmar. Compilation was done using mostly 1:500,000 to 1,000,000-, partly 1:1,500,000-scale geological maps. A compiled original map of 6 sheets was prepared at a scale of 1:1,500,000. As this original map is too large for publication (291 cm high and 203 cm wide), it was decided to reduce the size of the published map. Two sheets of 1:3,000,000-scale map were published. Each of the two sheets, the eastern (Sheet 1) and western (Sheet 2) halves, has a height of 109 cm and a width of 78.5 cm with 5cm overlapping area. There is also an appendix (Sheet 3), which contains "Map Showing Tectonic Division", "Index for Columnar Sections", "Columnar Sections" and "Sources of Data".

Geology of East Asia is very complicated, and there occur rocks of various ages and types in this area. Different map unit divisions have been adopted by countries and also by areas in one country. Preparation of a unified standard for classification of rocks of this whole area was a huge task. The division was simplified so that the map would not be too complicated, and the legend, which is shown in the right-bottom corner of Sheet 1, was also simplified. The legend is drawn in a so called "matrix format" (Fig.1). In this format, rocks are roughly divided into two types: one type is sedimentary, extrusive and metamorphic rocks and the other type is intrusive rocks. They are also divided on the basis of their ages. The ages of the source rocks are



* Age of terrigenous clastic sediments is shown in case of accretionary complex which includes blocks of older rocks such as basalt, limestone and chert of oceanic origin.

Fig.1. Legend

assigned for metamorphic rocks. Apart from these divisions, there is a division of continental, continental and marine, and marine origins for sedimentary rocks, and a division according to rock types for extrusive and intrusive rocks. In the Asian continent, it is difficult to discriminate metamorphic rocks from non-metamorphic rocks through the whole area. So metamorphic units are not shown. However, metamorphic rocks in island arcs are divided into two types, low to intermediate pressure/temperature type and high pressure/temperature type. Distribution of accretionary complexes is also shown in Taiwan, the Japanese Islands and Sikhote Alin.

The geological map clearly shows regional differences of geology, but it is not sufficiently clear where and how the geology changes and the implication of the changes is not easy to understand. For clarifying these points, a tectonic division map is represented on Sheet 3 (Fig.2).

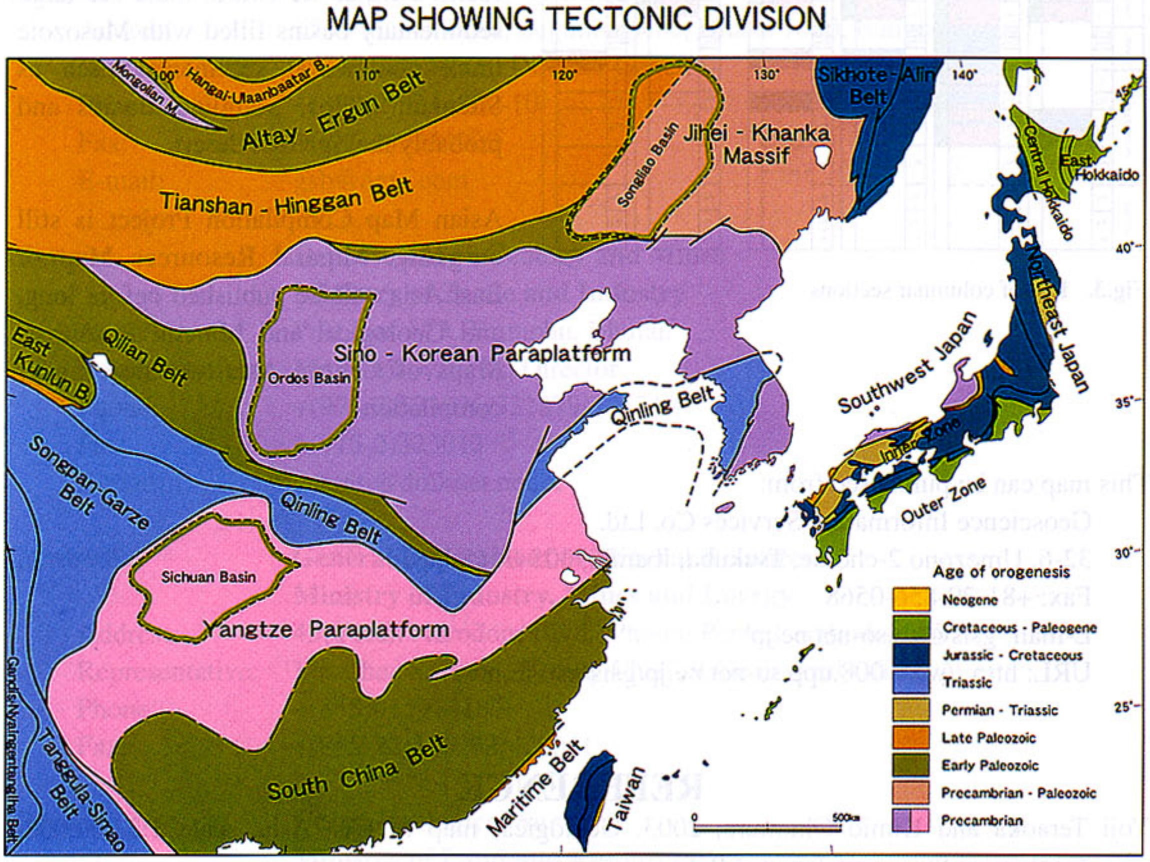


Fig.2. Tectonic division map

This map shows 21 geological provinces of this area. Most of the tectonic division follows the generally accepted current geoscientific thinking, but it differs partly, namely the Qinling Belt between the Yangtze and Sino-Korean Paraplatforms extends eastward from the Shandong Peninsula to the middle part of the Korean Peninsula, and then sharply bends southwestward.

In order to facilitate understanding of the map, Sheet 3 also includes 63 columnar sections for representative locations in the 16 main geological provinces to show crystalline basement, sedimentary and extrusive rocks (Fig.3). Division of continental, continental and marine, and marine facies is shown for each of sedimentary and extrusive rocks. The sedimentary rocks are classified into of carbonate, carbonate and clastic, and clastic facies. The extrusive rocks are divided into felsic, intermediate, and mafic rocks.

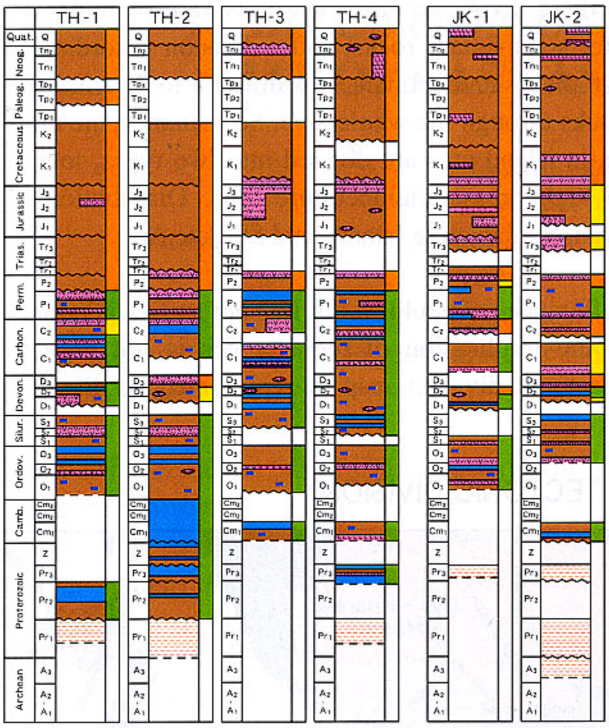


Fig.3. Part of columnar sections

This map would stimulate and enrich your imagination. There is a strong contrast between island arc areas such as the Japanese Islands and Taiwan, and the eastern part of the Asian Continent: yellow, yellow-green and bluish colours are dominant in the island arc areas with red spots in places, while reddish colours are prevailing in the eastern part of the Asian Continent, where widely occur Precambrian metamorphic and Precambrian to Mesozoic felsic intusive rocks. Further westward, there are large sedimentary basins filled with Mesozoic thick continental sediments, such as Sichuan, Ordos, Songliao Basins and probably that in Gobi desert.

Asian Map Compilation Project is still on-going. Mineral Resources Map of East Asia will be published before long, and Geological and Mineral Resources Maps of Central Asia, are now under compilation.

This map can be purchased from:

Geoscience Information Services Co. Ltd.
32-6, Umezono 2-chome, Tsukuba, Ibaraki, 305-0045 Japan
Fax: +81-29-856-0568
E-mail: gsis@kb.so-net.ne.jp
URL: http://www008.upp.so-net.ne.jp/gsis/gsis-E.htm

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As of 1 March 2004

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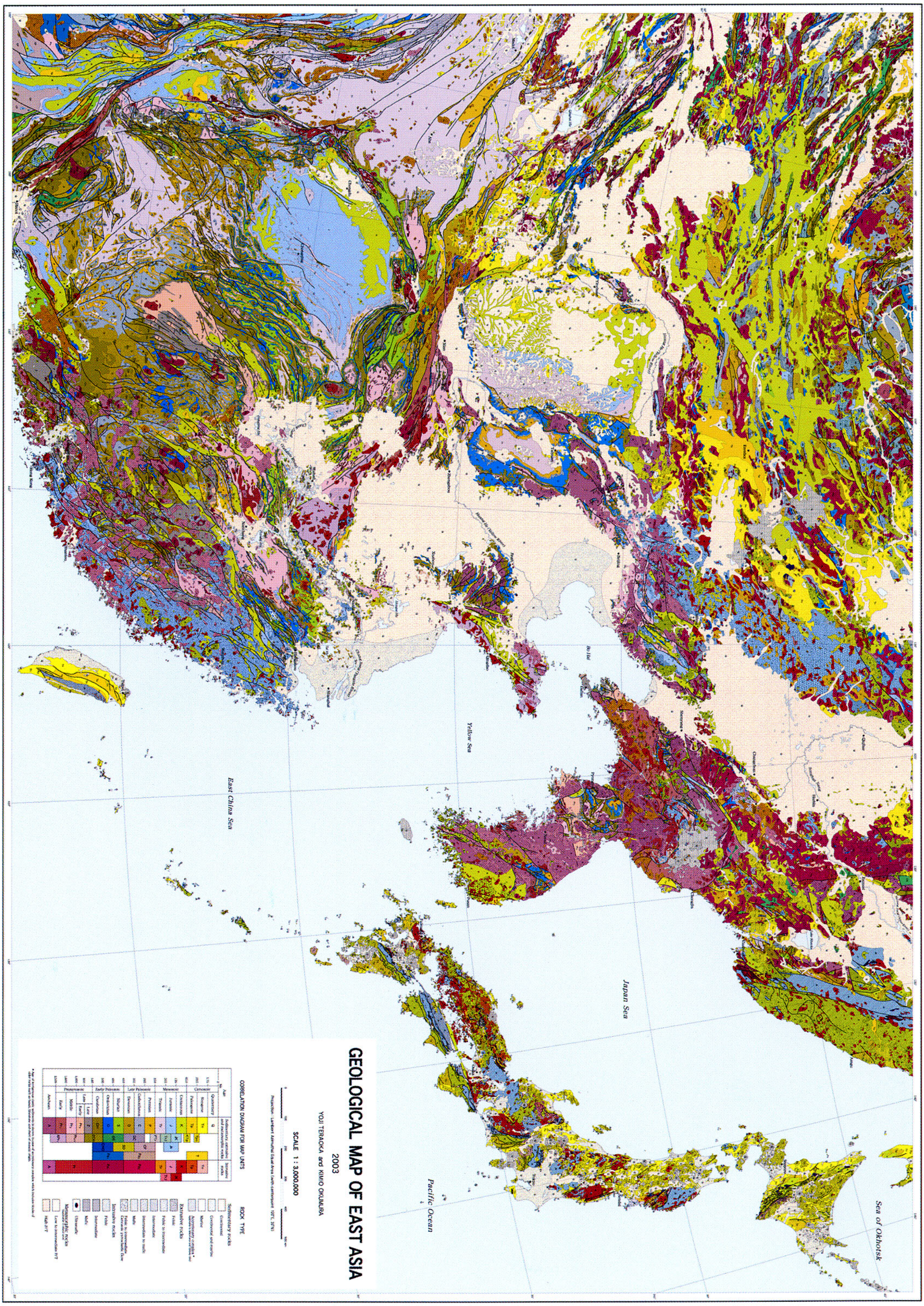

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