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Preliminary Neotectonic Map of Onshore-offshore Taiwan

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ABSTRACT

The diversity of the research in earth sciences leads to a multisource approach to investigate the surroundings of Taiwan. Various data sets combined by a Geographical Information System (GIS) enable us to propose an integrated neotectonic map of onshore-offshore Taiwan. Several technical problems arise during the compilation of this map, such as the homogeneity of scales, projections and geodetic systems used, the validity and precision of each data set (line and pixel) and document, and the integration of qualitative and quantitative documents.

Various types of information are taken into account in this approach, such as topography and bathymetry, geology (lithology, structure), geophysics (gravimetry, magnetism, etc.), geodesy (levelling, GPS, etc.), remote sensing and field works. This multisource approach has been applied to data sets both onland and offshore Taiwan, and has resulted in a preliminary neotectonic map of onshore-offshore Taiwan. This map provides a better comprehension of the geodynamic phenomena that affect Taiwan, and contributes significantly to the relations of the offshore structures and their corresponding reactivated extensional structures onshore (for instance, the Tainan, Taihsi, Okinawa, and Huatung basins).

This document should benefit both academic research (structural and active fault maps) as well as the applied geological implications (such as natural hazards mapping and evaluation of geotechnic works).

(Key words: Neotectonic map, Active faults, Structural geology, Remote sensing, Geographical information system, Earth science data base, Onshore Taiwan, Offshore Taiwan.)

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1. INTRODUCTION

Generally, marine and land geologists are members of two distinct scientific communities working on a common object separated only by shoreline. Our goal here is to link the data, analyses and interpretations of these works together in a synthesized document: a neotectonic map of onshore-offshore Taiwan. In order to achieve this goal, we have chosen here a multi-source Geographical Information System (GIS) approach, because (1) it restitutes truly the data geometry that comes from various origins; (2) it provides cartographic quality outputs, and (3) it is easy to improve the results by updating the database.

In the past ten years, we have been working progressively toward establishing an Earth Science database of onshore-offshore Taiwan using a GIS. This database integrates different data sets from various sources (1) to better constrain the geology, the lithology (ages, geological units) and the geometry of structures (location, activity, characterization and quantification, such as offsets, shortening, etc.); (2) to have a better idea of the erosion balance between onshore and offshore Taiwan; and (3) to give informative and accurate documents for land development, such as maps of active faults, information on vertical and horizontal ground motions, etc.

The philosophy of GIS is to combine documents from different sources (e.g., maps in different projections, geodetic systems, and scales, seismic line drawings, well logs, fault slip analyses, field mappings). For instance, the combination of both geological and geophysical data of onland Taiwan has revealed major previous unknown structures, such as NW-SE transfer fault zones in the Foothills (Deffontaines et al. 1994, 1997).

The aim of this paper is to present a preliminary version of the neotectonic map of Taiwan compiled using a GIS. We will introduce the methodology of our work, and the status of the Taiwan Earth Science Database under construction (but, we will not go through a detailed description of it), present the neotectonic map compiled, discuss the major features and limits of this map, and finally suggest the tasks which need to be done in the future.

2. GEODYNAMIC SETTING

Taiwan is the site of an active subduction-collision between the Philippine Sea and the

Eurasian plates. East of Taiwan, the Philippine Sea plate subducts northwestward beneath the Eurasian plate along the Ryukyu arc-trench system. In contrast, south of Taiwan, the Philippine Sea plate, bounded by the Luzon volcanic arc, overrides the Eurasian plate along the Manila Trench. The subduction south of Taiwan is transformed into a collision northward onshore Taiwan. The obliquity between the Chinese continental margin (Eurasian plate) and the Luzon volcanic arc (Philippine Sea plate) causes a progressive migration of the active collision towards the south (e.g., Biq 1972; Bowin et al. 1978; Wu 1978; Suppe 1981; Ho 1986). According to GPS measurements, a convergent rate of 81 mm/yr along a northwestly direction between the Philippine and Eurasian plates was recorded (Yu et al. 1997). That is why active faulting and neotectonics are major concerns in Taiwan.

Furthermore, onshore Taiwan, the high amount of precipitations and numerous typhoons of this tropical climate strongly erode the mountain ranges, in contrast to the syn-tectonic depositional processes that exist offshore. Both processes may be revealed from the Taiwan neotectonic map.

In order to better constrain the Taiwan geodynamic settings and the geometries of active folds and faults, we establish an earth science database covering both offshore and onshore Taiwan. This database leads to a preliminary neotectonic map (Fig. 1), as explained below.

3. METHODOLOGY

We have collected many geological and geophysical documents, photos, images and maps, and combined them together using the Intergraph Microstation MGE GIS software. The documents collected were initially in different forms (articles, maps, pictures, figures, tables, data files, etc., in both analog and digital formats). In particular, maps, remote sensing images and pictures are in different scales (local or regional), projections (local or international), and geodetic systems. All these documents need to be uniformized before combining them. The Intergraph Microstation MGE GIS software was chosen because it provides facilities to modify image geometries and projections, and to calculate specific aspects such as digital elevation model (DEM). In this database, the WGS84 geodetic reference system is used to combine onshore and offshore data, as it is commonly used worldwide.

Six steps are involved in generating this neotectonic map:

3.1 Data Acquisition

First, we gather information from the bibliography, including all the available published geological and geophysical maps, offshore seismic sections, published well log information, etc. Then, we synthesize our own published and unpublished field observations, mostly acquired under the Taiwan-France earth sciences cooperation framework since 1981. Remote sensing data such as ERS, JERS, SPOT, and Landsat images were also purchased and analyzed in order to obtain a multi-temporal complete coverage of Taiwan.

3.2 Data Validation and Precision

Whenever possible, we check all the elements, such as faults, fold axis, and lithology, to be part of the database, and assign weight to represent the degree of validity for each element. Sometimes misfits between different data sets appeared during this compilation, then we had to make choices and take other elements into consideration. For example, we look carefully for the available seismic lines in addition to the field mapping results to better constrain structural maps.

The validity of the neotectonic map depends on the accuracy of the upstream work. The resulting accuracy depends on the accuracy of the initial documents and generally ranges from 20 m to 1 km.

3.3 Data Processing

The analog documents were manually digitized or scanned into digital forms first, then all the digital data were corrected for geometry (taking anchor point in each document) in order to have the same projection and geodetic system (WGS84). Both raster (pixels) and vector (lines) data are taken into account, even though superimposition of the raster data is difficult.

3.4 Data Combination

We combine coherent information in order to establish specific maps, such as the neotectonic map of onshore-offshore Taiwan. The resulting scales of the documents have to be coherent with the primary documents used.

3.5 Data Output

The resulting files and documents may be printed out in A4 to A0 sizes by various printers, and at various scales, ranging from 1:25,000 to 1:2,500,000. These maps and other documents are then ready for detailed analyses and interpretation.

3.6 Data Base Updating

The system of the earth science database makes it easy to update and to extract information for specific purposes.

4. TAIWAN EARTH SCIENCE DATABASE (TESDB)

The data considered here, extracted from the database, cover numerous aspects of the earth sciences in Taiwan, including:

4.1 Oro-hydrographic Aspects

Morphology: The onland topography and offshore bathymetry of Taiwan are combined. Different scales and ground resolutions are used herein, from raw data for the orography (extracted and digitized from the ONC navigational charts and GEBCO bathymetry maps) to produce very precise datasets onshore (Taiwan DEM) and offshore (Lallemand et al. 1997; Liu et al. 1998).

Drainage networks: They were manually extracted from 1:100,000 topographic maps then digitized manually. The drainage network map reveals drainage anomalies and the misfits (Deffontaines et al. 1994, Lee et al. 1997).

Erosion balance: Major rivers are presently studied, looking carefully at sediment loads and runoffs for the last 30 years that give indications about the onshore erosion balance. In order to better constrain the balance of onshore-offshore erosion, a comparison between onshore outputs and offshore deposits is considered. Numerical methods are also used in order to better constrain the onshore erosion.

4.2 Geological and Neotectonics Aspects

Geology: Both lithology (facies and ages) and structures (folds and faults) are taken into account by digitizing the existing geological maps published by the Central Geological Survey and in other publications. The scale depends on the initial documents that show variable local accuracy depending on the accessibilities of the fields. Both local and regional scales have been taken into consideration in this work.

Structural and tectonic aspects, stresses and strains: The structural aspects have been taken into account by specific methods, such as field cross-sections, palinspastic balanced cross-sections, borehole break-outs, Calcite twins analyses, fault slip analyses, etc.

Neotectonics: A morpho-neotectonic map of onland Taiwan has been published by Lee et al. (1997), who gathered information from the orography, the drainage and the aerial SLAR data. This map reveals morpho-tectonic features of onland Taiwan. Mapping of active faults and folds are conducted. Published GPS geodetic works (Yu et al. 1997), multi-temporal levelling data, plus specific studies on seismotectonics (e.g., Kao et al. 1998, 2000) have all been taken into consideration.

4.3 Geophysical Aspects

Magnetic and gravity anomaly data, and seismic reflection profiles have been included in the database. In order to avoid a crowded appearance, we did not put shallow seismicity (depth < 35 km) on the map, though those data (extracted from the Central Weather Bureau) are included in the database.

5. DISCUSSION

Several interesting structural features can be easily identified on the map and are described below from south to north:

— Structural characteristics of the Manila accretionary prism to the south of Taiwan. The thrust-and-fold belts which are affected by strike-slip faults are the dominant structural features. The structural trend turns from N150°E to N020°E when the accretionary prism encroaches the Eurasian passive margin (Liu et al. 1997).

— The relations of the Tainan basin faults and the deformation front. The Mio-Pliocene E-W to N070°E trending normal faults in the Tainan Basin are presently reactivated into right-lateral strike-slip faults near the deformation front (Deffontaines et al. 1997).
— The indentation structures around the Peikang High in the Chiayi area, especially in Meishan and Hsiaomei area.
— The numerous NW-SE transfer fault zones in the Foothills contribute significantly to the tectonic setting of the Foothills. These fault zones have to be considered in seismic hazards studies (Deffontaines et al. 1994, 1997).
— The Reactivation of the Taihsi basin faults northwest of the Sanyi-Miaoli-Hsinchu belt. The Mio-Pliocene E-W to N070°E trending normal faults in the Taihsi basin are reactivated in right-lateral strike-slip transpressive motion, as shown for instance by the Hsinchu fault.
— The active N-S extensional structures in the Southern Okinawa Trough are connected to a right-lateral strike-slip fault (the Lishan fault) in the Ilan plain. Volcanisms have also been observed, such as the small Kueishan Tao island east of the Ilan plain.
— The folds and faults structures in the Ryukyu accretionary prism (Lallemand et al. 1999) and along the coastal range of Taiwan (Malavieille et al. in press).

This neotectonic map (Fig. 1) not only shows the synthesized results of published and unpublished data, it also shows the gaps in the data sets, misfits between superimposed documents, different interpretations, and certain detailed structural relations. The offshore littoral zone appears to be poorly mapped along the western coast of Taiwan, such as the area west of Taichung and Peikang High, inside the 12 miles zone offshore Tainan and Kaohsiung, and southeast of LanYu island to the SE of Taiwan. The structure of the Huatung basin east of Taiwan remains unclear. Onshore Taiwan, the structures of the Central Range away from the main cross-island highways are also poorly known (grey and blue colors on Fig. 1, legends 24-26 and 28).

6. LIMITATION OF THE MULTISOURCE APPROACH

Many data sets are presently confidential, and could not be included in the database. They include the high resolution (40 m ground resolution) onland DEM data and offshore swath bathymetry data, and the detailed local geological maps, well log information, and onshore and offshore seismic lines of the Chinese Petroleum Company. Those data sets, once declassified, would provide critical information to understand the recent (post-Miocene) orogenic developments.

This map also shows that data gaps exist offshore especially near the shoreline. Filling these data gaps is critical for better constraining the links between erosion and deposition processes, which occur both onland and at sea in this extremely active environment (high uplift and fast erosion rates resulting huge amount of sediment being transported to sea), and the links between onshore and offshore geology.

7. CONCLUSION

The establishment of the Taiwan Earth Science Database under the framework of a long-term collaboration program between France and Taiwan leads to the generation of a preliminary neotectonic map of onshore-offshore Taiwan (Fig. 1). This map provides a bird's eyes view of the major structures (active or not) in and around Taiwan. It also shows the importance of linking onshore and offshore geology and structures, and highlights the importance of future geological and geophysical tasks in the littoral zone that is poorly known at present.

This cartography also leads to scientific questions, such as the chronology of the deformations and the structural settings during the mountain building processes.

Finally, concerns about seismic hazards have been raised recently after the Chichi earthquake (September 21, 1999). The integrated approach using a GIS is a compulsory approach to help manage sustainable development in Taiwan. The earth sciences database established using a GIS software leads to new insights in the structures and geodynamics of Taiwan and their associated natural hazards (such as landslides, active faults, volcanic monitoring, coastal evolution, etc.) on Taiwan, as presented in this neotectonic map of onshore-offshore Taiwan.

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