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TOWARD A COMPREHENSIVE STRATIGRAPHIC SYSTEM OF THE COASTAL RANGE, EASTERN TAIWAN

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ABSTRACT

Recent mapping efforts show that the stratigraphic scheme proposed by Teng and Wang (1981) can be successfully applied to the entire Coastal Range. According to this scheme, rocks of the Coastal Range can be divided, in ascending order, into (1) Tuluanshan Formation, andesitic volcanics and associated volcastic sedimentaries; (2) Lichi Formation, ophiolite-bearing mélange; (3) Fanshuliao Formation, turbidites dominated by volcanic detritus, fossil remains, and quartzo-feldspathic grains; (4) Paliwan Formation, turbidites dominated by metasedimentary rock fragments; (5) Pinanshan Conglomerate, alluvial to shallow marine conglomerates dominated by metamorphic rock fragments. A number of subunits are proposed for detailed mapping of Tuluanshan and Paliwan rocks. Available paleontological and radiometric data allow reasonable delineation of biostratigraphy and chronostratigraphy. The geological history of the Coastal Range, as shown by its stratigraphic record, can be satisfactorily accounted for by the collision between the Luzon arc and the Chinese continent.

INTRODUCTION

The geology of the Coastal Range has been studied for more than sixty years. Early mapping work was initiated by Japanese geologists who compiled a number of preliminary geologic maps (Hosoya, 1915; Hosoya and Deguchi, 1916; Usami, 1939a, b; Ooe, 1939). Hsu (1956) published the first complete geologic map of the Coastal Range with an integrated stratigraphic scheme which became a solid basis for later studies. By incorporating stratigraphic information obtained in the 60s and 70s (Chang, 1967a, 1968, 1969; Yen, 1967, 1968, 1969; Biq, 1969; Teng, 1979, 1980a, Page and Suppe, 1981), Teng and Wang (1981) revised Hsu's stratigraphic scheme and proposed a plate tectonic interpretation of the stratigraphic record of the Coastal Range. Recent mapping efforts attested to the validity of the revised stratigraphic scheme and successfully applied it to the whole Coastal Range (Figs. 1 and 2). The purpose of this paper is to elucidate the content of the revised stratigraphic scheme according to the modern stratigraphic code (International Subcommission on Stratigraphic Classification, 1976, 1987), and to update the stratigraphic information on the basis of recent studies. It is hoped to establish a comprehensive stratigraphic scheme to facilitate future geologic studies in the Coastal Range.

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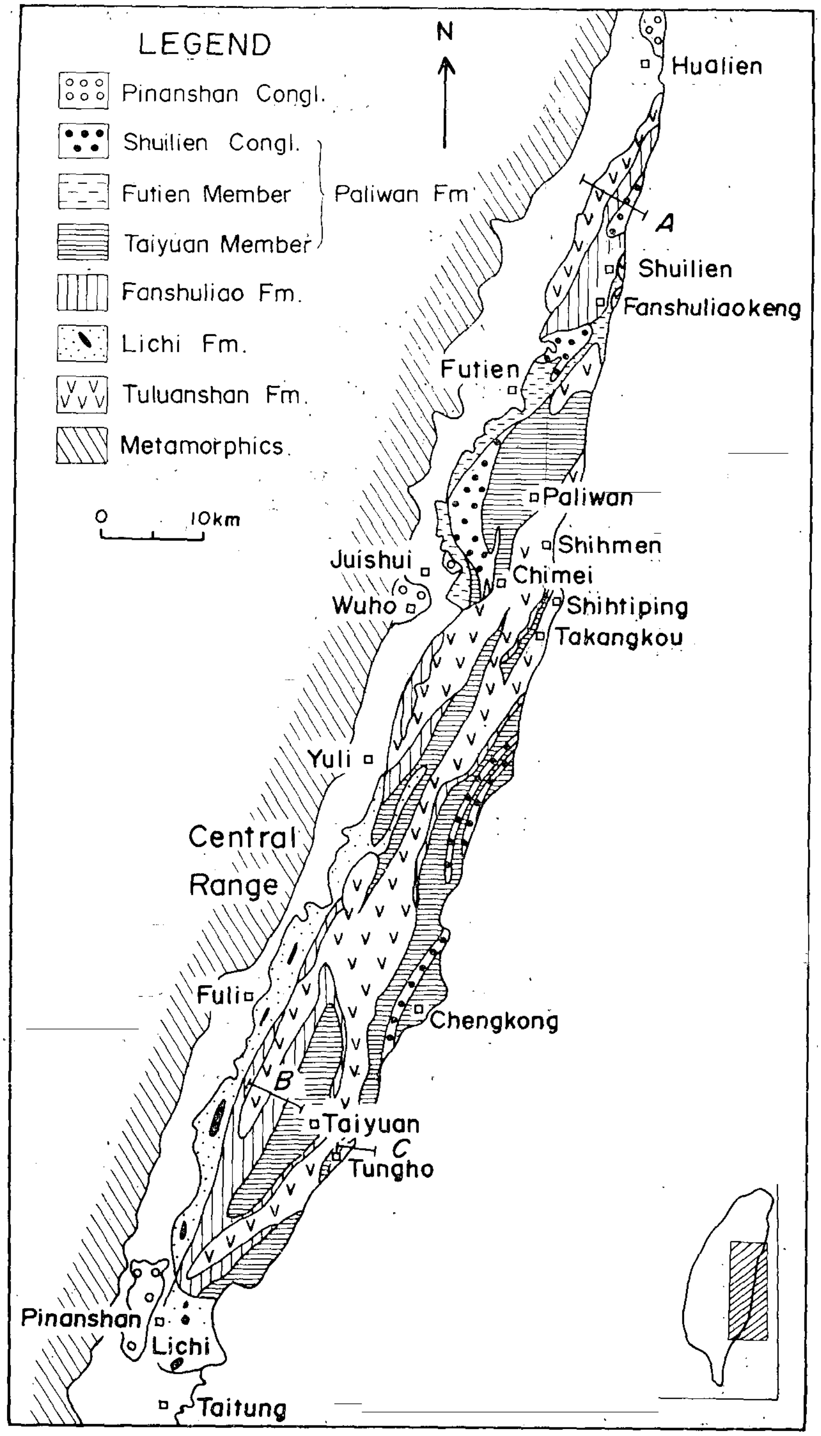


Fig. 1. Geologic sketch map of the Coastal Range. *A:* Yenliao section; *B:* West Taiyuan section; *C:* Tungho section.

LITHOSTRATIGRAPHY

The rocks of the Coastal Range can be divided into five major rock units as described below (Fig. 2):

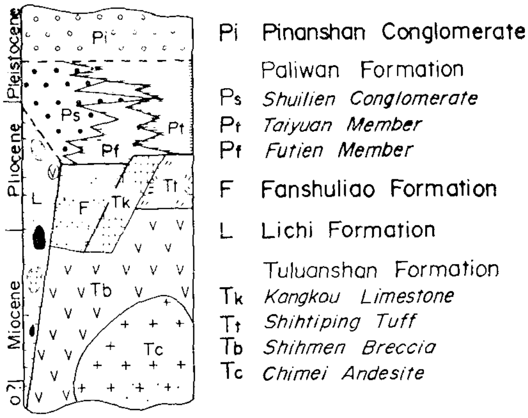


Fig. 2. Stratigraphic scheme of the Coastal Range.

Tuluanshan Formation

As proposed by Hsu (1956), the Tuluanshan Formation includes a variety of volcaniclastic rocks, such as agglomerates, tuffs, conglomerates, sandstones, and associated limestones. Except the massive andesites exposed in the Chimei area (Fig. 1), almost all the andesitic rocks of the Coastal Range are grouped in the Tuluanshan. Since massive andesites and volcaniclastic sequences are intimately associated (Wang and Yang, 1974; Yang, 1987; Song and Lo, 1988), it is advisable to group them in one rock unit (Teng and Wang, 1981). Hence the Tuluanshan Formation is redefined to comprise all the andesitic rocks and associated volcaniclastic sedimentary sequences in the Coastal Range. The section along the Hsiukuluan-chi from Chimei to Takangkou that exhibits the most complete sequence of Tuluanshan rocks is proposed as the type section (Fig. 1). The geology of the type section is detailed in Wang and Yang (1974), Song and Lo (1988), and Chen and Wang (1988).

The Tuluanshan Formation occupies a large portion of the Coastal Range and underlies most of the non-pyroclastic sedimentary sequences. Because the base is not exposed, the total thickness is unknown. The maximum thickness estimated from the type section is about 1500 m. Since the exposed Tuluanshan rocks represent only the upper part of the volcanic sequences (Song and Lo, 1988), it is believed that more andesitic rocks are buried underneath. Lithologically the Tuluanshan Formation is dominated by volcanic breccias with subordinate lavas and tuffs, and minor intrusives. Thin lentils of volcaniclastic limestones are often found near the top of the volcaniclastic sequences. A number of informal subunits have been proposed locally but not all of them fit the purpose of regional mapping (Chang, 1967b; 1969; Yen, 1968, 1969; Wang and Yang, 1974; Song and Lo, 1988; Chen and Wang, 1988). According to preliminary investigations, it is possible to subdivide the Tuluanshan rocks according to their major rock types, i.e., breccia, lava, tuff, and limestone. By adopting the priority of Hsu (1956), Chang (1967b), and Song and Lo (1988), it is suggested that *Chimei Andesite* (massive lavas and intrusives), *Shihmen Breccia* (breccias), *Shihtiping Tuff* (tuffs) and *Kangkou Limestone* (limestones) be members of the Tuluanshan Formation. These subunits crop out well in the type section and serve as a good basis for mapping in the Shihmen-Chimei-Takangkou area (Fig. 1) (Song and Lo, 1988). Mapping of these subunits in other parts of the Tuluanshan awaits future work.

Lichi Formation

As proposed by Hsu (1956), the Lichi Formation is composed of chaotic mudstones intermixed with exotic blocks of various size and lithology. The area near the Lichi village is proposed as the type area (Fig. 1) (Hsu, 1956). The Lichi Formation rims around the southwestern verge of the Coastal Range with only one small outcrop reported from Futien in the northern Coastal Range (Teng, 1980b). The contact between the Lichi and other rock units is believed to be mostly faults (Hsu, 1976), but coherent interdigitation with strata of other units might exist locally (Page and Suppe, 1981; Li, 1984; Barrier and Muller, 1984). The maximum apparent thickness is estimated to be 1400 m (Hsu, 1956), which was supported by borehole information (Meng and Chiang, 1965).

The lithological features of the Lichi Formation are characteristic of a mélange (Biq, 1969, 1971; Hsu, 1976; Ho, 1977; Page, 1978; Teng, 1980b; Page and Suppe, 1981). The mudstones generally exhibit intense shearing but no distinct stratification. Crude layering of pebbly mudstones and coherent stratification have been reported locally (Chang, 1969; Liou *et al.*, 1977a; Page, 1978; Li, 1984; Barrier and Muller, 1984). The enclosed blocks may attain to kilometers in diameter and are generally angular in shape. Most of the small blocks (tens of meters in diameter or smaller) are heavily sheared but large blocks seem to remain intact. In terms of lithology, the exotic blocks can be grouped into three clans; the ophiolitic suite, including basic to ultrabasic rocks; the sedimentary suite, including sandstones, sandstone/shale interbeds, shales, and limestones; and the andesitic suite, including volcanic breccias, tuffs, and volcaniclastic turbidites (Hsu, 1976; Liou *et al.*, 1977b; Page and Suppe, 1981).

Fanshuliao Formation

First proposed by Chang (1969) and then redefined by Teng (1980a), the Fanshuliao Formation is composed of alternating sandstones and shales dominated by volcanic detritus, fossil remains, and quartzofeldspathic particles (Teng, 1980a). The drainage area of the Fanshuliao-chi west of the Fanshuliaokeng village is proposed as the type area (Fig. 1) (Chang, 1968; Teng, 1980a; Wei and Cheng, 1982). The Fanshuliao Formation conformably overlies the Tuluanshan Formation and underlies the Paliwan Formation. The thickness varies considerably, from less than 100 m to over 1200 m. The Fanshuliao strata are mainly fine-grained turbidites equivalent to facies D of Mutti and Ricci Luchi (1972). Pebbly mudstones and slide blocks are quite common and slump structures are almost ubiquitous. Although facies characteristics vary locally, no distinctive lithological change can be used for further subdivision.

Paliwan Formation

First proposed by Chang (1969) and then redefined by Teng and Wang (1981), the Paliwan Formation consists of intercalated conglomerates, sandstones, and shales that are dominated by metasedimentary rock fragments, such as slate and metasandstone. The drainage area of the Paliwan-chi surrounding the Paliwan village is proposed as the type area (Fig. 1) (Chang, 1968). The Paliwan Formation conformably overlies both the Fanshuliao and the Tuluanshan Formations. The thickness ranges from 1000 m to over 4000 m.

The Paliwan Formation includes a whole gamut of facies of a deep-sea fan (Teng, 1982). Most of the Paliwan deposits are well stratified in spite of abundant slump features. Generally speaking, the Paliwan Formation exhibits a southward fining trend, with conglomerates dominating in the north and sandstones in the south (Teng, 1982). According to the relative abundance of conglomerate, sandstone, and shale, the Paliwan Formation can be divided into three subunits (Figs. 1 and 2). The conglomeratic beds, grouped as the *Shuilien Conglomerate* by Usami (1939a), are hereby retained as a member. The sandstone-dominated beds are grouped as the *Taiyuan Member* which crops ont well in the drainage area of the Mawuku-chi near the Taiyuan village (Fig. 1). The shale-dominated strata are included in the *Futien Member* which crops out well in the area east of the Futien village (Fig. 1).

Pinanshan Conglomerate

First proposed by Ooe (1939), the Pinanshan Conglomerate is named for the conglomerates exposed in the Pinanshan area north of Taitung (Fig. 1). Patches of conglomeratic deposits similar to the Pinanshan are disseminated in the Longitudinal Valley and used to be treated as different rock units (Hsu, 1956). The conglomerates exposed around the Milun terrace near Hualien were named the Milun Conglomerate by Usami (1939a) and were correlated with those exposed around the Saopa (now named Wuho) terrace as a unit much younger than the Pinanshan (Hsu, 1956). In fact, these conglomerates are comparable in lithology and age and can be regarded as stratigraphic equivalents and grouped into the Pinanshan Conglomerate (Teng and Wang, 1981). However, the Milun Conglomerate can be preserved as a member for its facies difference. The Pinanshan Conglomerate is not in direct contact with other rock units of the Coastal Range except with the Lichi Formation along the Pinanta-chi where the contact is interpreted as a fault (Tan, 1941; Hsu, 1976; Page and Suppe, 1981). The total thickness of the Pinanshan is unknown because the base is not exposed. The exposed thickness is estimated to be as much as 3250 m (Page and Suppe, 1981).

The Pinanshan Conglomerate is composed of layered conglomerates interbedded with sandstones and minor shales. Most of the lithic fragments are metamorphic rocks derived from the Tananao Complex. The conglomerates exposed in the Pinanshan, Wuho and other spots in the Longitudinal Valley are believed to be nonmarine deposits, whereas the Milun Conglomerate is mainly a shallow marine deposit. The Pinanshan strata are structurally deformed and can be readily distinguished from the recent flat-lying alluvial deposits in the Longitudinal Valley in spite of their lithological similarity.

BIOSTRATIGRAPHY

Besides early paleontological studies (Hanzawa, 1932; Hsu, 1956), the biostratigraphy of the Coastal Range was first established by Chang (1967a, 1968, 1969, 1975) in terms of foraminiferal assemblages. Chi *et al.* (1980, 1981) furnished nannoplanktic data and set up the nannobiostratigraphy. Up to the present, the fossil successions were not well documented and a few discrepancies between foraminiferal and nannofossil data still remain to be solved. The biostratigraphy hereby proposed is mainly a summary of the published data (Fig. 3) (Chang, 1967a, 1968, 1969, Chang and Chen, 1970; Huang, 1969; Chi *et al.*, 1980, 1981; Chang and Chi, 1983).

The microfossil data of the Tuluanshan Formation are mainly concentrated on the Kangkou Limestone and associated tuffs in the upper portion. In spite of arguments arising from larger foraminifers (Hanzawa, 1932; Chang, 1968), nannofossil data show that the type section of the Kangkou Limestone is equivalent to NN 11 (Chi *et al.*, 1980, 1981) and possibly to NN 11 to NN 15 (Cheng and Wei, 1983). Recent foraminiferal analyses show that the type section can be bracketed in the upper part of zone N 18 (Huang *et al.*, 1988). Because the Kangkou is composed of a number of individual limestone bodies, the fossil assemblages may vary locally. For instance, the limestone at Yangwangshing includes foraminifers indicative of lower N 19 (Huang *et al.*, 1988) and the body at Tungho (Tungho Limestone of Chang, 1967b) can be correlated

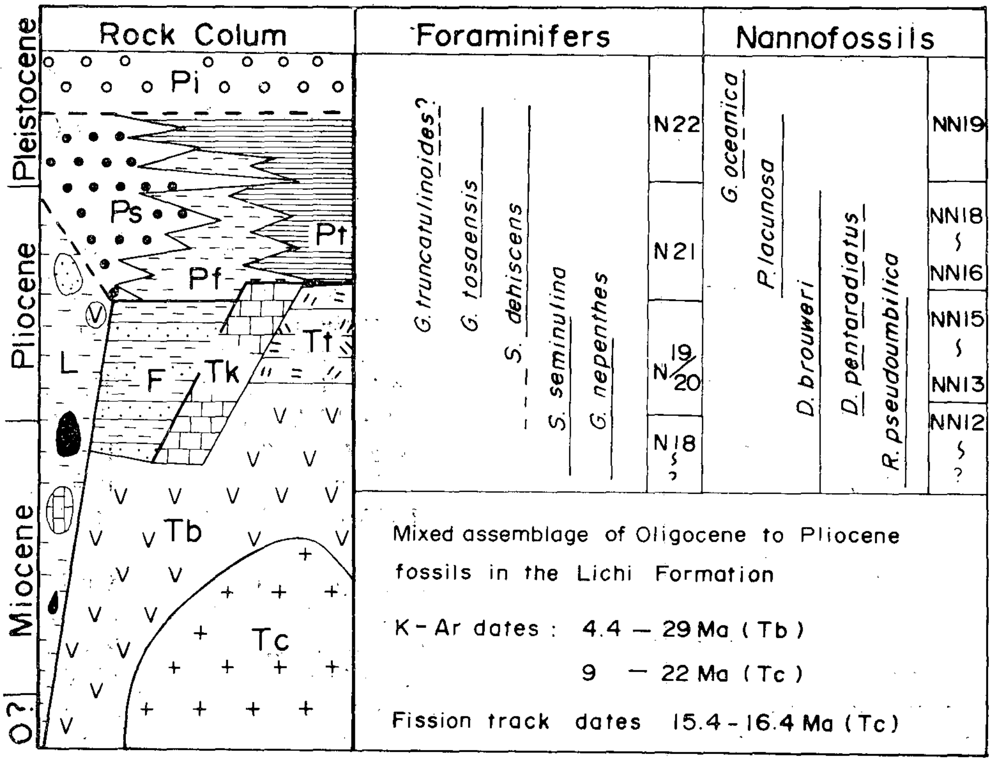


Fig. 3. Biostratigraphic and chronostratigraphic chart of the Coastal Range. See text for explanation. Formational labels same as Fig. 2.

with N 19 to N 21 (Chang, 1969; Chen and Wang, 1988). Hence as a whole, the Kangkou Limestone is approximately equivalent to the upper NN 11 to NN 15 or to the upper N 18 to lower N 21. For the volcaniclastic deposits, nannofossils and foraminifers so far recovered mainly pertain to the NN 11 and N 18 (Chang, 1968; Chi *et al.*, 1981; Song, 1986). Nevertheless, nannofossils indicative of NN 15 were also recovered from the cavity filling of Tuluanshan lavas (Chi and Chu, 1982), and those of NN 2 from red shales intercalated in the Tuluanshan-equivalent volcanics on the Lanshu island (Chi and Suppe, 1985).

The fossil assemblage of the Lichi Formation is as chaotic as its lithology. Mixed assemblages of foraminifers of N 14 to N 21 and nannofossils of NN 3 to NN 15 have been recovered from the mudstones and enclosed sedimentary blocks (Chang, 1967a, 1969; Chi, 1982; Barrier and Muller, 1984). Paleogene nannofossils were also reported (Chi, 1982). Because no stratigraphic sequence can be recognized in the Lichi, the biostratigraphy cannot reasonably delineated.

The Fanshuliao Formation, although fossiliferous, is difficult to delineate biostratigraphically because of the ominipresent slump features. Based on available information, the Fanshuliao can be generally correlated with N 18 to N 19 and with NN 11 to NN 15 (Chang, 1967a, 1968, 1969; Chi *et al.*, 1981; Wei and Cheng, 1982; Barrier and Muller, 1984). No distinct biostratigraphic sequence can be recognized within the Fanshuliao yet.

The Paliwan Formation yields fairly abundant fossils that warrant decent biostratigraphic analyses. In terms of foraminiferal zonation, the Paliwan Formation can be bracketed in N 21. The nannofossil assemblages, however, indicates a range from NN 16 to NN 19, which is equivalent to foraminiferal zones N 21 and NN 22. Although Chang (1969) claimed no positive occurrence of *G. truncatulinoides* indicative of N 22, the presence of *G. oceanica* in the nannofossil assemblages clearly indicates that a large portion of the Paliwan is equivalent to NN 19 (Chi *et al.*, 1981). Moreover, some primitive forms of *G. truncatulinoides* were reported and the lack of true *G. truncatulinoides* is probably attributed to ecological or diagenetic effects (Huang, 1964; C. Y. Huang, 1988, personal comm.). Up to now, no detailed sequential analyses have been attempted. Nevertheless, preliminary data show a fairly good biostratigraphic sequence within the Pailwan (Chi *et al.*, 1981).

The Pinanshan Conglomerate is rather poor in fossils. In the Pinanshan type area, nannofossils indicative of NN 11 were found but regarded as reworked specimens (Chi *et al.*, 1983). The terrestrial nature of the conglomerates supports the reworked origin of the marine fossils. Foraminifers indicative of N 19 were found in the shales underlying the conglomerate (Chang, 1967a). In the Hualien area, nannofossils indicative of NN 20 were recovered from the Milun Conglomerate (Chi *et al.*, 1983). Based on the available data, the Pinanshan Conglomerate can only be roughly correlated with the upper NN 19 and the NN 20 (Chi *et al.*, 1983).

So far, not much work has been done on the environmental aspects of fossils in the Coastal Range. Chang and Chen (1970) made a preliminary comparison in paleobathymetry shown by foraminiferal assemblages of the Paliwan Formation along the Hsiukuluan-chi section. Ingle (1975), on the basis of Chang's foraminiferal data, interpreted the Fanshuliao and Lichi Formations as lower bathyal deposits. Wei (1978) did a preliminary paleoecological analysis on the Kangkou Limestone in the Takangkou area and proposed a reef setting for deposition.

CHRONOSTRATIGRAPHY

The age of the Tuluanshan Formation can be delineated in terms of radiometric dating and biostratigraphy (Fig. 3). According to K-Ar dates (Ho, 1969; Juang and Bellon, 1984; Richard *et al.*, 1986), most of the Tuluanshan volcanics are Miocene in age with some extending into late Oligocene (29 Ma) and early Pliocene (4.5 Ma). Fission track data of the Chimei andesite fall in the range of 15.4 to 16.4 Ma (Yang, 1987). Up to the present, there are no biostratigraphic or radiometric data other than one K-Ar date for the Oligocene age (Richard *et al.*, 1986). Whether the age of Tuluanshan volcanics extends into the Oligocene is an open question. Nevertheless, since the exposed Tuluanshan rocks only represent the upper portion of the volcanics, it would not be surprising to find Oligocene volcanics in the lower portion. The age of the upper part of Tuluanshan volcanics clearly extends into early Pliocene as shown by radiometric dates and fossil data. The age of the Kangkou Limestone is biochronologically well constrained in the range from 5.4 to 3 Ma. In general, the top of the Tuluanshan Formation and its stratigraphic equivalents in the Luzon arc exhibit a north-to-south time-transgressive trend. In the northern Coastal Range, the age of the top Tuluanshan is near the Miocene/Pliocene boundary, whereas in the southern Coastal Range, it is early late Pliocene. Further down south, late Pliocene to Pleistocene volcanics were found in Lutao and Lanshu, and late Quaternary volcanism was reported from the Batan, Babuyan, and Luzon islands (Hamburger *et al.*, 1982; Balce *et al.*, 1982; Bachman *et al.*, 1983; Richard *et al.*, 1986).

The age of the Lichi Formation is hard to define on account of the disorganized biostratigraphic nature. However, the dominance of Miocene fossils in both foraminiferal and nannofloral assemblages indicates that the Lichi deposits are mainly Miocene in age (Hsu, 1956; Chang, 1967a, 1969; Chi, 1982; Teng and Lo, 1985). Since no Pleistocene index fossils have been found, the top of the Lichi should be older than the Pleistocene. Based on available fossil data, the top of the Lichi seems to fit in the lower N 21 or upper NN 15 which roughly corresponds to 3–2 Ma (Huang, 1969; Chi, 1982). The lower age limit of the Lichi is almost impossible to delineate due to the lack of recognizable stratigraphic sequence. If ignoring the mixing nature, the age of the Lichi could be interpreted as old as Oligocene in terms of the fossil assemblages (Teng and Lo, 1985).

The age of the Fanshuliao Formation roughly spans the latest Miocene to early Pliocene as shown by its biostratigraphic range (Fig. 3). The top of the Fanshuliao Formation can be bounded by the first appearence of *G. tosaensis* and *P. lacunosa* at the base of the Paliwan Formation, which is equivalent to about 3.0 Ma (Berggren *et al.*, 1985). The age of the base of the Fanshuliao is not well constrained owing to the lack of decent sequential control. According to available data, the base could be as old as 5.4 Ma, approximately equivalent to the uppermost portion of N 18 or NN 11.

The age of the Paliwan Formation can be well delineated in terms of biostratigraphic data. The base is equivalent to the NN 15/NN 16 boundary or N 19/N 21 boundary, indicative of an age of 3.0 Ma. The top falls in the upper part of NN 19, after the reapearence of *G. oceanica* (Chi *et al.*, 1980, 1981), which is younger than 0.9 Ma. Paleomagnetic study shows that the top goes up into the Brunhes, indicating an age younger than 0.7 Ma (Lee *et al.*, 1988).

By extrapolating the sediment accumulation rate, the age of the top can be as young as 0.65 Ma.

The age of the Pinanshan Conglomerate is difficult to delineate owing to the lack of datable marine fossils. Nannofossils indicative of NN 20 recovered from the Milun Conglomerate offer an age younger than 0.46 Ma (Chi *et al.*, 1983). However, neither the base nor the top of the Milun is exposed and available fossil data were not sufficient to provide constraints on the age range. Based on stratigraphic correlation with coeval rock sequences of western Taiwan, Teng (1987b) put the base and top of the Pinanshan at 0.37 Ma and 0.14 Ma respectively.

STRATIGRAPHIC RELATIONS

Although some pre-Tertiary metamorphic basement was proposed for the Coastal Range (Hsu, 1956; Yen, 1967), no unequivocal contact between the metamorphic rocks of the Central Range and rocks of the Coastal Range has been documented in the Coastal Range *per se*. The only possible rock unit deposited on the metamorphic basement is the Pinanshan Conglomerate which is distributed in the Longitudinal Valley instead of the Coastal Range. In terms of the high Bouguer gravity values associated with the Coastal Range (Bowin *et al.*, 1978; Chang and Hu, 1981; Hu and Chen, 1986), it is unlikely to have a continental basement underneath.

The interrelations among the Tuluanshan, Fanshuliao, and Paliwan Formations pose an interesting point on the Coastal Range stratigraphy. Wherever overlain by the Fanshuliao deposits, the Tuluanshan Formation is composed of debris-flow type breccias and turbidites (Fig. 4). On the other hand, the Tuluanshan limestones and associated tuffs are often overlain by the Paliwan Formation directly, instead of the Fanshuliao deposits. The Fanshuliao Formation, although overlying the Tuluanshan volcanics, is chronostratigraphically equivalent to the upper part of the Tuluanshan volcanics and limestones (Fig. 2). This coevalness lends support to the interpretation that the Tuluanshan limestones and tuffs represent the shallow-water volcanics and fringing reefs around the arc islands and the Fanshuliao turbidites and underlying Tuluanshan debris-flow deposits represent the deep-water deposits in the forearc basin (Teng and Wang, 1981; Teng and Lo, 1985; Chen and Wang, 1988).

Although the contact between the Lichi Formation and other rock units is believed to be mostly faults (Hsu, 1976; Teng and Lo, 1985), depositional contacts between the Lichi and the Fanshuliao (referred to as the Takangkou by others) were reported by Page and Suppe (1981), Li (1984), and Barrier and Muller (1984). Recent observations show that some of the Fanshuliao strata may onlap the Lichi mélange, probably indicating the stratigraphic contact between the forearc basin deposits and the trench mélange at the trenchward margin of the forearc basin (Teng and Lo, 1985).

The Paliwan Formation conformably overlies both the Tuluanshan and Fanshuliao Formations. The nature of Fanshuliao-Paliwan contacts varies with the facies character of the Paliwan Formation (Fig. 4). In the northern Coastal Range, the Shuilien Conglomerate overlies the Fanshuliao with a sharp contact. In the south, the facies contract across the Fanshuliao-Paliwan boundary is not as dramatic but slightly transitional. The Tuluanshan-Paliwan contact is generally characterized by the sequence of shallow-water volcanics and/or

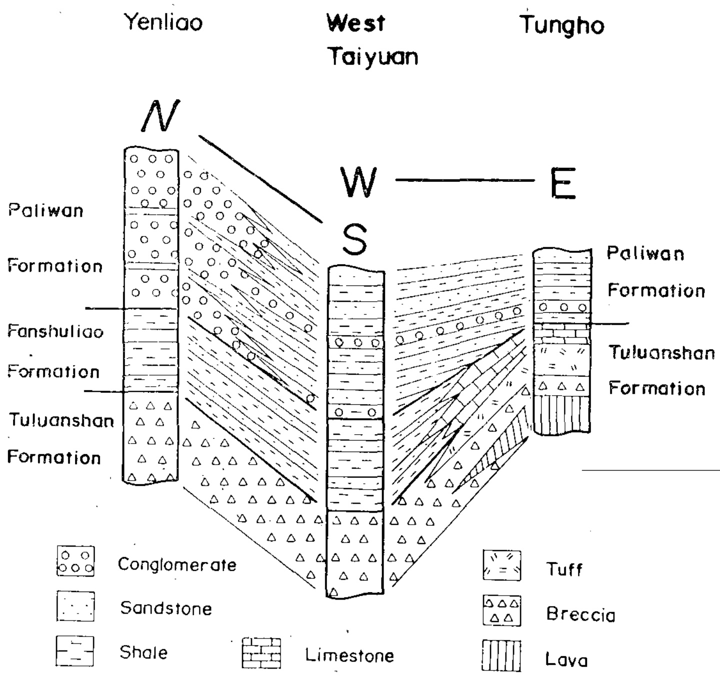


Fig. 4. Stratigraphic relations and spatial facies variations of the Tuluanshan-Fanshuliao-Paliwan sequences. Locations of sections shown in Fig. 1.

associated limestones followed by deep-marine mudstones and turbidites. The facies change associated with this contact is rather drastic and involves significant basin deepening (Chen and Wang, 1988; Huang *et al.*, 1988). The diachronous nature of the Tuluanshan-Paliwan contact manifests an onlapping relationship between the two (Chen and Wang, 1988). The facies variations of the Paliwan Formation indicate the deposition of submarine fans in the forearc basin fed by the channels from the north (Teng, 1982). The onlapping relation of Tuluanshan-Paliwan contact reflects infilling of the forearc basin by Paliwan deposits (Chen and Wang, 1988).

The Pinanshan Conglomerate has no observable contact with any other rock units except the fault contact with the Lichi. The restricted distribution of the Pinanshan in the Longitudinal Valley indicates that the Pinanshan was deposited in the Valley rather than the *Coastal Range basin proper* and the discontinuous Paliwan-Pinanshan facies transition implies an unconformity in between (Teng, 1987a).

GEOLOGIC HISTORY

The stratigraphic record of the Coastal Range can be satisfactorily accounted for by the collision between the Luzon Arc and the Chinese continent (Teng and Wang, 1981; Teng and Lo, 1985; Teng, 1987a). Downthrusting of the crust of the South China Sea beneath the Philippine Sea plate which commenced in the Oligocene gave birth to the modern Luzon arc-trench system and has manipulated the entire collisional processes (Karig, 1973; Teng and Lo, 1985;

Teng, 1986). From the Oligocene to the Miocene, arc magmatism brought about thick sequences of Tuluanshan volcanics and sediment offscraping along the trench piled up the subduction complex of the Lichi mélange (Fig. 5a). Because the arc was situated far away from the continent, no continental influence can be perceived in the Tuluanshan arc.

In the late Miocene, the arc moved close to the continent and began to override the continental margin sediment (Fig. 5b). As more and more sediment was dragged into the subduction zone, magmatic activities might be hampered so that arc volcanism dwindled. Biogenic sedimentation began to prevail in the basins around the arc to deposit the fringing reefs of the Kangkou Limestone and the volcanogenic bioclastic turbidites of the Fanshuliao Formation. Continental material might also be involved in magma generation to induce more silicic eruptions (Juang and Chen, 1988; Chen *et al.*, 1988). In the meantime, a large amount of continental sediment was scraped off and added to the accretionary wedge which grew up rapidly to become an outer arc. Through time the outer arc emerged above the sea level and was able to supply continental material to the forearc basin to deposit the quartzofeldspathic sediments of the Fanshuliao Formation.

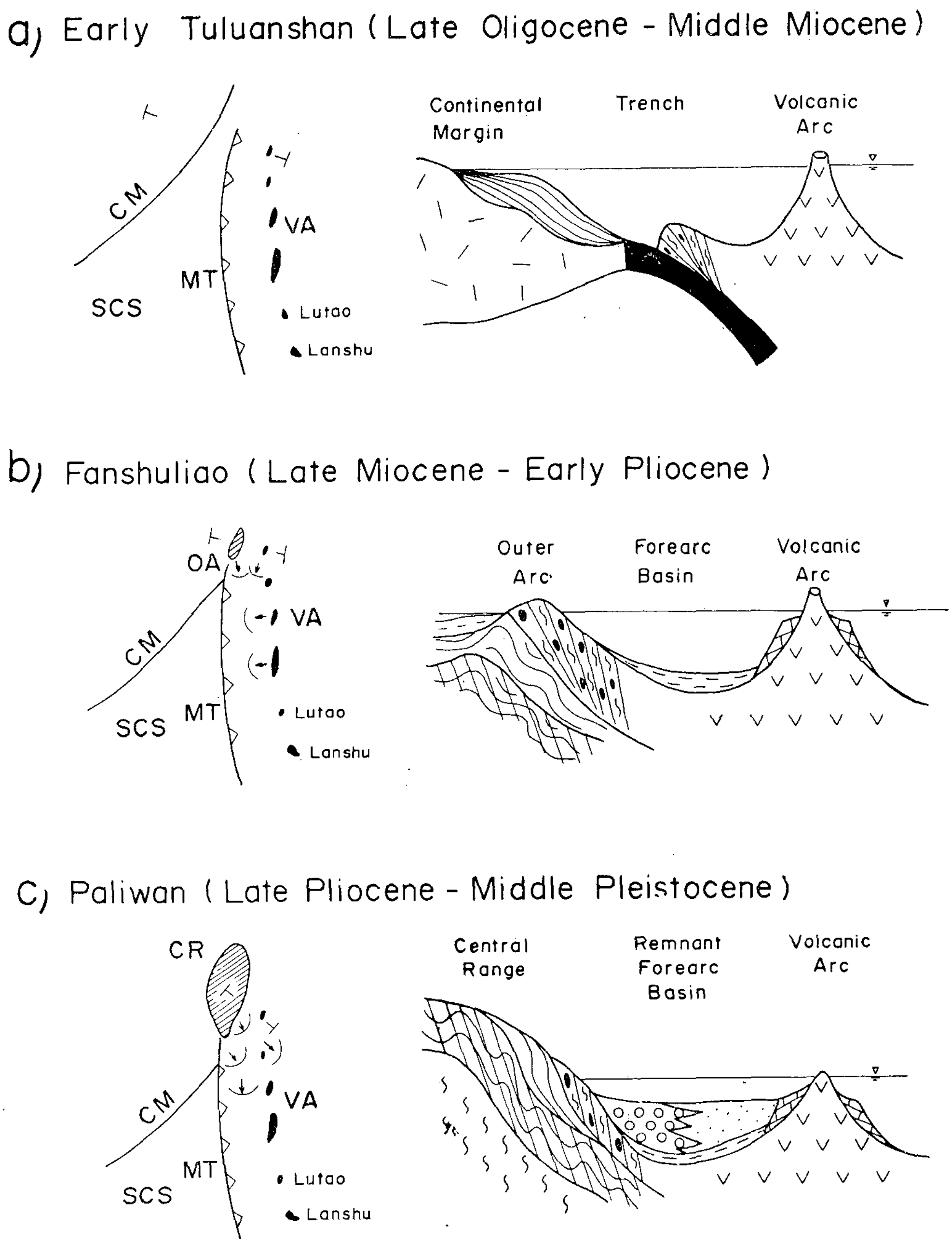
In the late early Pliocene, the arc had overridden so much continental material that subduction could no longer proceed (Fig. 5c). Drastic arc-continent collision squeezed up the continental margin to form the Central Range. A large amount of coarse-grained metasedimentary rock fragments were eroded down from the Central Range and fed into the remnant forearc basin to deposit the conglomerates and turbidites of the Paliwan Formation. Arc volcanism almost died out in the north but dragged on in the south so that volcaniclastic detritus are occasionally intercalated in the Paliwan deposits.

In the middle Pleistocene, the collision deformed the remnant forearc basin to form the Coastal Range and only a small trough remained between the Central Range and the Coastal Range (Fig. 5d). Alluvial and nearshore sediments of the Pinanshan Conglomerate were laid down in the remaining trough and were then deformed to the present configuration by continual collision (Fig. 5e).

CONCLUSIONS AND DISCUSSIONS

Based on past studies and recent mapping efforts, a quintuplet stratigraphic scheme with a complete geologic sketch map of the Coastal Range can be established. The definition, type area and facies characteristics of each rock unit are elucidated and a number of subunits are suggested for future mapping. The biostratigraphy and chronostratigraphy are also delineated on the basis of available data. The stratigraphic record of the Coastal Range can be satisfactorily accounted for by the collisional processes between the Luzon arc and the Chinese continent.

The stratigraphic information herein presented represents the synopsis of available data and is by no means complete. The stratotype of each rock unit remains to be established and the biostratigraphy and chronostratigraphy can be improved. The validity and applicability of the stratigraphic scheme need to be continually scrutinized by future studies.



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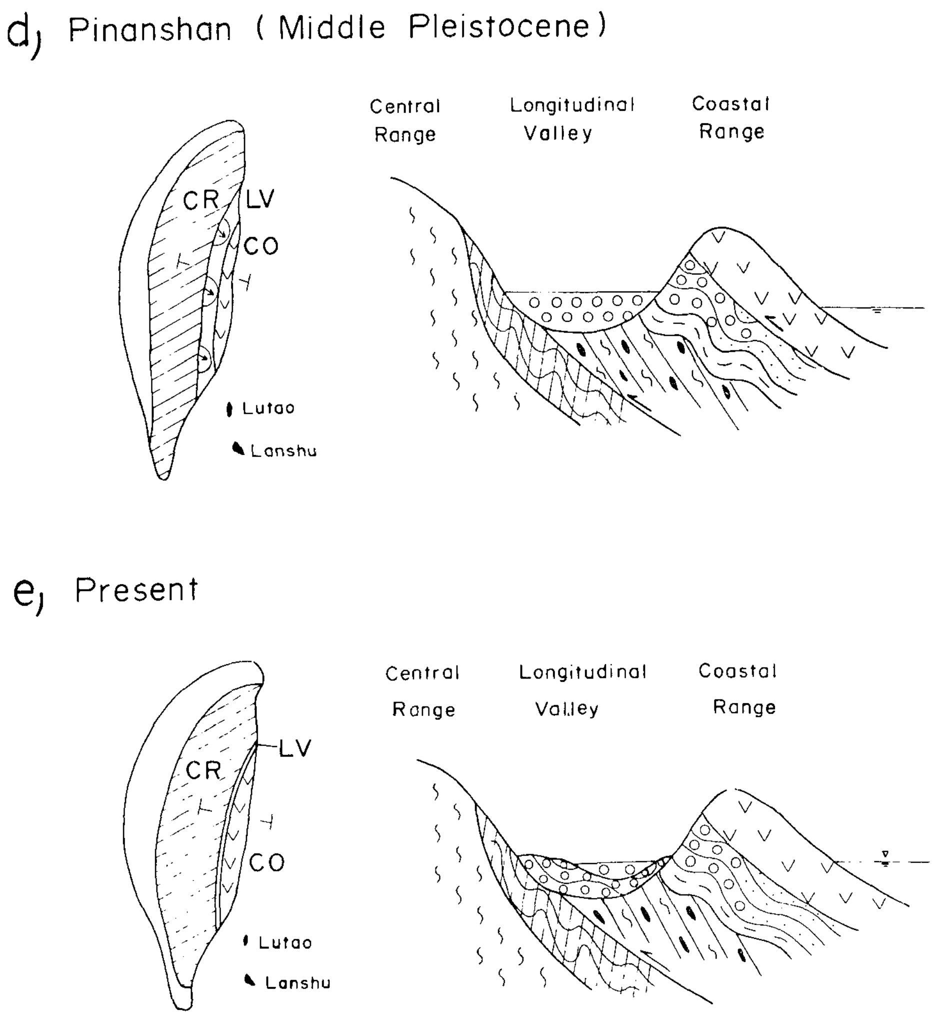

CM Continental Margin
CO Coastal Range
CR Central Range
LV Longitudinal Valley
Sediment Dispersal
MT Manila Trench
OA Outer Arc
SCS South China Sea
VA Volcanic Arc

Fig. 5. Geologic evolution of the Coastal Range in plate tectonic framework of arc-continent collision.

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海岸山脈地層體系全觀

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節　要

基於最近之野外工作，鄧屬予與王源（1981）所提出的地層體系已可成功地應用於整個海岸山脈。依此地層體系，海岸山脈岩層由老到新可分爲：㈠都巒山層，安山岩質火山岩及其隨伴之火山碎屑沉積岩；㈡利吉層，含蛇綠岩之混同層；㈢蕃薯寮層，含火山碎屑、化石及石英、長石等礦物之濁流岩；㈣八里灣層，含變質沉積岩屑濁流岩；㈤卑南山礫岩，含變質雜岩岩屑之礫岩。都巒山層和八里灣層又可分爲數個岩段以作爲詳細製圖之依據。基於現有之古生物及放射性定年資料可將生物地層及時代地層釐定。海岸山脈之地層紀錄可以弧陸碰撞之機制加以詮釋。