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MESOSCOPIC STRUCTURES DEVELOPED IN THE LICHI MELANGE DURING THE ARC-CONTINENT COLLISION IN THE TAIWAN REGION

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ABSTRACT

In eastern Taiwan, the Lichi Melange forms a chaotic mudstone belt with well-developed scaly foliation. After detailed field investigations on the mesoscopic structures, it is suggested that those structures have developed during the processes of arc-continent underplating and collision between the Eurasian and Philippine Sea plates.

The Lichi Melange is mainly composed of mudstone with inclusions of sandstone and ophiolitic blocks with varying degrees of fracturing. The mudstone matrix was pervasively sheared resulting in scaly foliation with small slickensided surfaces and striations. The rake of the striations is within the range of 0°-20°, and it plunges either to the north or south in the sense of a left-lateral movement. Besides, the sandstone blocks in the foliated matrix are pervasively fractured, and their long axes are generally parallel to the striations of the scaly foliation in the mudstone matrix. The matrix and blocks have apparently suffered from the same stress field. These structures may have occurred collectively in a strong shearing zone during the collision.

Three types of fractures, namely, hybrid, extension (crack) and cataclastic shear (web structure) fractures, can be identified in the sandstone blocks. The extension crack in some blocks is well cemented with calcite and is oblique at a high angle to the bedding. These extension fractures are commonly accompanied by normal faulting. In light of the research of deep-sea core, it is suggested that the crack in the sandstone represents an intensive hydrofracture that occurred in the coherent strata beneath or above the shear zone in the accretionary prism. The web structure is a network of cataclastic shear planes in sandstone that are characterized by broken and less than average grain size relative to the surrounding rocks. The web

and crack structures commonly observed in sandstone blocks within the melange that exhibit some degree of lithification and healing. The fact that the extension fracture and web structures cross cut by the hybrid fracture and scaly foliation indicates that it formed before the collision. It is suggested that these structures reflect tectonic deformation and stratigraphic disruption during the underplating process. Thus, based on the mesoscopic structures, the structural style of the Lichi Melange is best described as a tectonic melange rather than a sedimentary melange or olistostrome.

Key words: Lichi Melange, arc-continent collision

INTRODUCTION

The word "melange" was originally used as a descriptive term with no genetic connotation but a term which denotes rock with "blocks in matrix" texture (Greenly, 1919). Melange may originate through sedimentary, tectonic, diapiric or combinations of these processes (Raymond, 1975, 1984) and is generally considered representative of an ancient subduction complex and plate boundary. Detailed analyses of the mesoscopic structures in the Lichi Melange are necessary to solve its genetic problem which is the key to unravel the tectonic history of the arc-continent collision. The following discussion focuses on mechanism in the formation of the Lichi Melange in the Coastal Range, eastern Taiwan.

The Lichi Melange is exposed along the Longitudinal Valley of eastern Taiwan for about 150 km. The melange is composed predominantly of intensely sheared mudstone with inclusions of isolated blocks of sandstone, shale, tuff, andesite and ophiolite. The inclusions range in size from a few millimeters to 4 km in their longest dimension; e.g. the Fukang sandstone block is at least 4 km long. These inclusions have been thought to come from the former passive continental margin (Page and Suppe, 1981; Chen, 1988), the collisional basin (Chen, 1988, 1991), the volcanic-arc (Page and Suppe, 1981; Teng and Lo, 1985; Ho, 1982; Barrier and Muller, 1984; Chen, 1988, 1991) and oceanic-crust materials (Biq,1971; Chai,1972; Liou *et al.*, 1976; Page, 1978; Page and Suppe, 1981; Suppe *et al.*, 1981; Teng and Lo, 1985; Chen, 1988, 1991; Chung and Sun, 1992). Most previous studies have stressed subduction-underthrusting as the chief mechanism and have suggested that the Lichi Melange evolved along a convergent plate boundary (Biq, 1971; Chai, 1972; Karig, 1973; Teng, 1980; Chen, 1988, 1991; Chen and Wang, 1988; Hsu, 1988). On the other hand, Ernst (1977), Page (1978), Page and Suppe (1981) and Pelliter and Stephan (1986) considered that it was originally a Miocene subduction product which was later removed to forearc area by slumping. Previous studies on the disrupted formation from uplifted convergent margins have brought up different interpretations as to the deformational mechanisms and their tectonic setting. Some geologists suggest that the stratum's disruption is a gravity-induced deposited formation (Page, 1978; Page and Suppe, 1981; Cowan, 1985). Others support the theory that the stratum's disruption is a tectonic product caused by shearing in a broad fault zone (Hsu, 1971).

The main purpose of this paper is to describe the mesoscopic structures observed in the outcrops that are relevant to the genetic interpretation of the Lichi Melange. This paper discusses in detail these mesoscopic structures because they appear to preserve the complete history of the subduction/collision sequence. The study also attempts to assess the mechanism of the melange between the ancient convergent plates.

GEOLOGICAL SETTING

The Coastal Range has been constructed the volcanic arc in the basement that is covered with sedimentary pile up to 4000 m in thickness. The depositional sequence of the Coastal Range has been divided into the three tectono-stratigraphic sequences of volcanic-arc deposits, orogenic sediments and subduction-collision complex: i.e. the Lichi Melange (Fig. 1).

Sequence 1, the volcanic-arc sediments (Tuluanshan Formation and Kangkou Limestone): It represents the Luzon volcanic-arc chain in the Miocene to early Pliocene resulting from the subduction of the South China Sea oceanic crust beneath the Philippine Sea plate. This sequence includes andesitic lava flow, volcanic breccia, tuff, epiclastic sandstone/conglomerate and limestone (Yen, 1958a, b, 1968; Chi *et al.*, 1981; Teng and Lo, 1985; Song and Lo, 1988; Chen, 1988; Chen and Wang, 1988; Chen *et al.*, 1990; Dorsey, 1992).

The Luzon arc, situated on the western margin of the Philippine Sea plate, has progressively moved towards the northwest due to plate motion. As soon as the northern part of the Luzon arc moved northward beyond about 21° N(lat.), because it left the northern end of the active Manila trench thereby ending its volcanism (Chen and Wang, 1988). At the beginning of the collision, the northern end of volcanic arc overrode the Eurasian continental shelf and slope as of 3 Ma in the late Pliocene (Chen, 1988; Chen and Wang, 1988).

Sequence 2, the orogenic sediments (Fanshuliao, Paliwan and Pinanshan Formations): Orogenic sediments of the flysch and molasse deposits that consist of conglomerate, sandstone, rhythmic sandstone/mudstone and mudstone, which appear to represent a series of deep-sea and alluvial fan systems deposited during the Plio-Pleistocene. This sequence, conformably or disconformably overlying the volcanic sediments and limestone, was deposited at the collision basin (Chi *et al.*, 1981; Chen and Wang, 1988; Dorsey, 1988, 1992; Dorsey and Lundberg, 1988). The sediments in the basins were dominantly derived from the orogenic belt of the proto-Central Range, which began to form in the west of the Coastal Range in the Plio-Pleistocene.

Sequence 3, the subduction-collision complex: The Lichi Melange mainly consists of a well developed phacoidally cleaved mudstone that contains a variety of disseminated exotic blocks of sandstone, shale, tuffaceous sandstone, andesite and ophiolite (Pl. 1A). Many andesitic and sedimentary blocks were originally deposited in the forearc and collisional basins. The Lichi Melange mainly contains fossils of nannofossils and planktonic foraminifera of the Miocene to Pleistocene age that may represent the younger phase of the Miocene to Recent episode of the arc-continent subduction/collision complex.

MESOSCOPIC STRUCTURES IN THE LICHI MELANGE

The Lichi Melange crops out in a belt 150 km long and 1-8 km wide along the eastern side of the Longitudinal Valley (Fig. 1). It occurs as a highly deformed complex that mainly yields Miocene to Pleistocene fossils that have been contributed to disruption the Mio-Pleistocene strata (Huang, 1969; Chang, 1967; Chi *et al.*, 1981; Chen, 1988). Typical outcrops in the

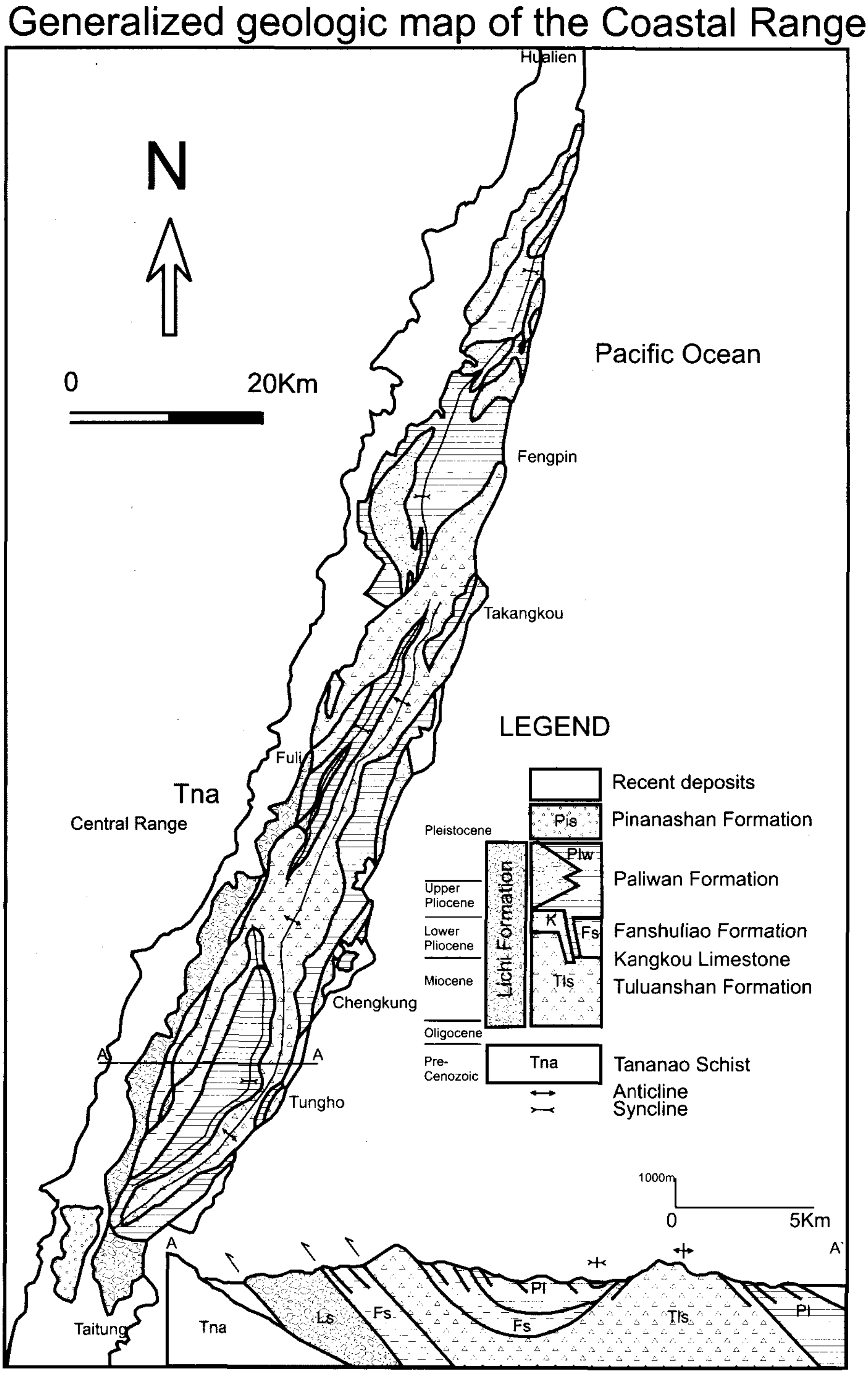


Figure 1. Geological map of the Coastal Range, eastern Taiwan.

Table 1. Characteristics of mesoscopic structures of the Lichi Melange

	Shear Fracture (scaly foliation)	**Extensional Shear Fracture (hybrid fracture)**	**Extension Fracture (crack)**	**Cataclastic Shear (web)**
vein			*	
cataclastic	*			*
annealing			*	*
orientation	northeast 10°-30°, steeply dipping	subperpendicular to the long axes of the block	perpendicular to bedding	random or subparallel to bedding
striation	plunging of 0°-20° to the north/south with left-lateral component			
fracture type	shear fracture	extension shear fracture	extension fracture	shear fracture

* exists

southern end of the Coastal Range contain elongate to ellipsoidal blocks that embedded in strongly foliated shaly matrix. The deformation of the melange is characterized by a variety of mesoscopic structures in matrix and blocks. The shaly matrix is organized by penetrative scaly foliation that has highly flash surfaces and striations. The sandstone blocks are transversed by many hybrids, extension (crack) and cataclastic shear (web structure) fractures. In this paper, the auther concentrates on the description of the mesoscopic structures (Tab.1) in the disrupted formation, attemptes to assess the deformational mechanism of the Lichi Melange and finally suggests possible deformation histories for their development.

Fabric of matrix

The shaly matrix of the melange consists of fine-grained pelitic materials that are characterized by penetrative foliation visible in the outcrop.

shear fracture (scaly foliation)

The penetrative foliation is polished and commonly slickensided which reflects a shear movement (Pl. 1B). The curviplanar surface of the foliation is also characterized by aligned minerals and striated lines. It has been reported earlier that the alignment of mineral grains accomplished the reorientation of the existing minerals by tectonic disruption in the deep-sea core (Moore *et al.*, 1986; Schoonmaker, 1986). From the abrasion of the country rocks, the striations in the Lichi Melange appear to be actual scratches. These foliated zones curve around with or subparallel to the lensoid blocks. The striations on the scaly foliation are also consistent with the long axes of the blocks. The foliation is defined by an anastomosing polished surface that is pervasive on a scale of a few millimeters to centimeters in width on average. The strike of foliation is dominantly in the range of 10° to 30° northeast, dipping verticaliy or at least steeply to the east (Fig. 2) (Chen, 1991; Chen and Lin, 1992). Striations are well developed with a consistent rake of 0°-20° and plunge either to the north or south with a left-lateral component (Barrier and Muller, 1984; Chen, 1991; Chen and Lin, 1992). According to the penetrative foliation and its consistent orientations, it is suggested that the Lichi Melange is tectonic origin. Similar results have also been found in other convergent margin terrains of the world (e.g. the Franciscian Complex: Hsu, 1974; Cowan,1974; south Alaska: Byrne,1984; south-western Japan: Taira *et al.*, 1982; Maltman *et al.*, 1993).

Fabric of blocks

The melange contains a wide variety of blocks of sedimentary, volcanic and ophiolitic rocks. Blocks of sandstone are by far the most common and are thought to have been mainly derived from the Miocene-Pliocene strata that are foreign to this now-disrupted terrain. Well-developed storm and turbidite sequences are common in the sandstone blocks that were originally deposited from the continental shelf to deep-sea fan. These blocks display intensively brittle deformations and have developed in a ductile-deformed mudstone matrix. They are commonly elongated to ellipsoidal in form and vary in size from a few millimeters to several kilometers in the longest dimension. The orientation of the long axes of the blocks is commonly consistent with the striation on the scaly foliation.

hybrid fracture (extensional shear fracture, joint)

The hybrid fracture is commonly present in the sandstone blocks and is penetrated by thin black shale veins. The offsets of hybrid fractures indicate normal-fault movement, and they are approximately perpendicular to the longest axis of the sandstone blocks (Pl. 2A). Sandstone blocks appear to have extended parallel to the long axis. The blocks are traversed by extensional shearing and bounded by simple shearing. The cross-cutting relationships among the hybrid fractures in the blocks and foliation fractures in the mudstone are interpreted to have formed contemporaneously in the sheared zone during the collision.

extension fracture (crack)

The extension fractures are also present in sandstone blocks. These conspicuous fractures are inclined at a high angle to the bedding and are entirely confined to the sandstone blocks (Pl. 2B). The cracks appear V-shaped and are regularly spaced at intervals of 2 mm to a few millimeters in width (Pl. 3A). The crack boundary is irregular and tapers downward or upward to the bedding plane. Crack forking and stepping commonly occur in the sandstone blocks and also as filled calcite veins. Roughly conjugate sets of cracks belong to normal faults with a displacement of a few millimeters to several centimeters and are filled with many brecciated

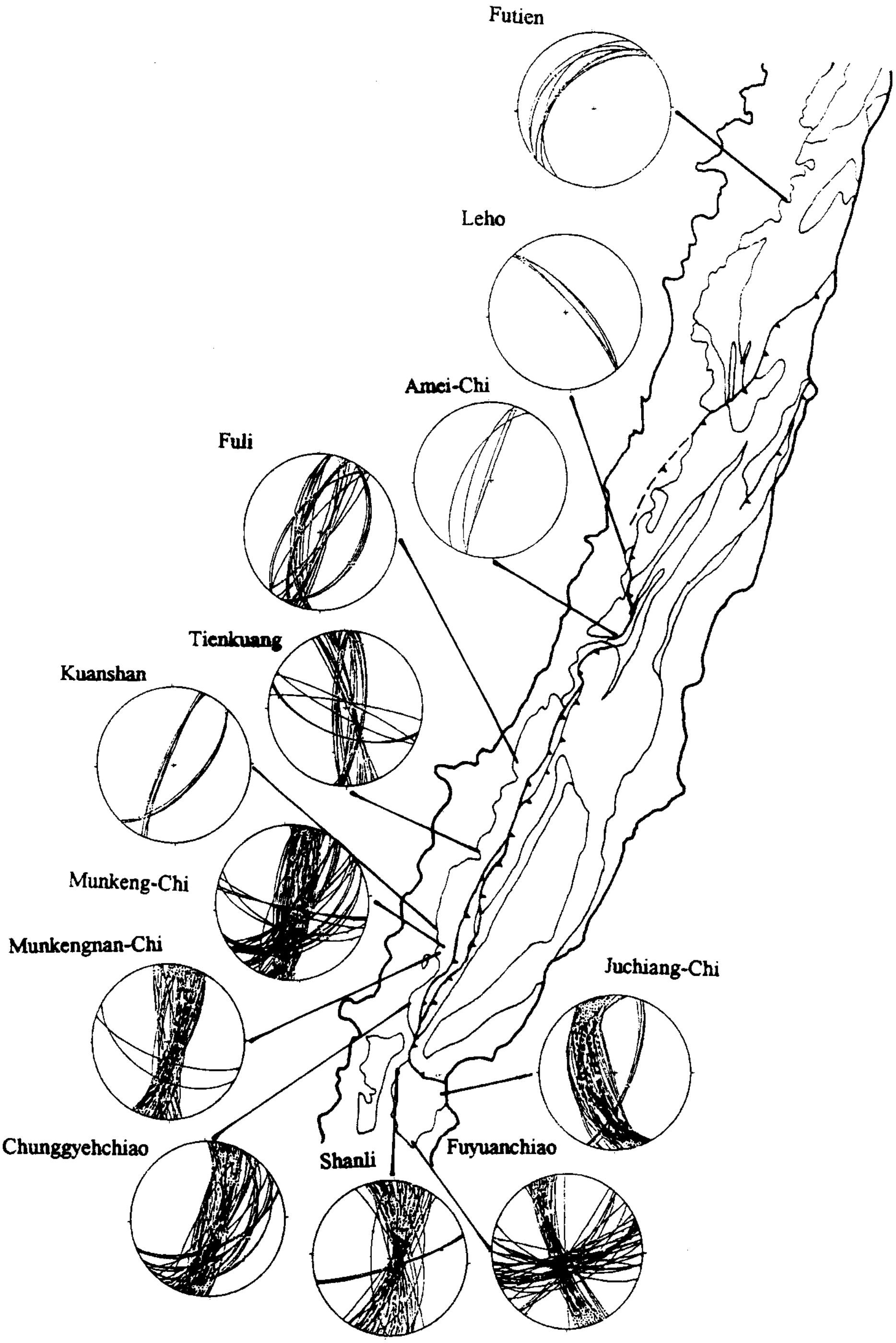


Figure 2. Stereographic plots (lower-hemisphere projections) of the orientations of all slickenlines/striations on the scaly foliation in the Lichi Melange.

fragments (Pl. 3B; Figs. 3, 4). The angular sandstone breccias, ranging in size from 1 mm to 2 cm, are lithified monolithologic breccias that are apparently derived from the wall rock of the sandstone blocks. The cracks and breccias are cemented or healed by calcite (Pl. 3B). The calcite veins and extension cracks always trend to be oriented perpendicular to the bedding plane of the sandstone. The orientation of these cracks and vein fractures suggest that σ_1 was high angle to the bedding. These veins and cracks are sometimes offset by hybrid fractures in the sandstone blocks. They are obviously not connected with the scaly foliation in the matrix and hybrid fractures in the blocks and are cross-cut by the hybrid fractures. Therefore, it is obvious that the above fractures were formed prior to the compressional shearing structures of the hybrid fractures and scaly foliation.

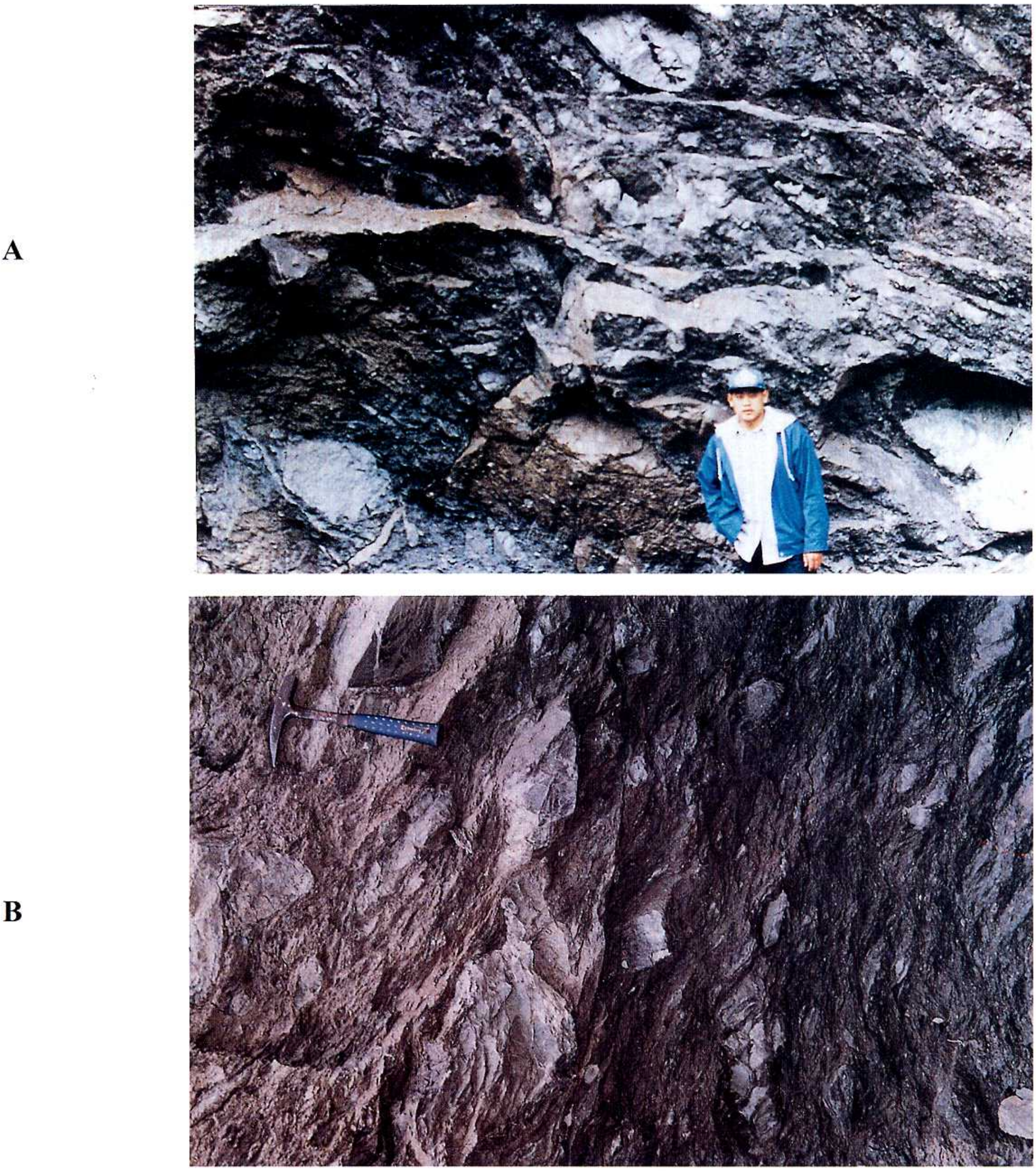
cataclastic shear fracture (web structure)

The web structure in the massive sandstone inclusions in the Lichi Melange is penetratively laced with a gray anastomosing zone (Pl. 4A) which in this paper is interpreted as a cataclastic shear band. The gray band is approximately 1 mm wide and is composed of comminuted grains sub-parallel to the band (Pl. 4A). Crushing and consolidation within the band caused the comminuted material to be harder than the surrounding rock. Displacement along individual shear zones rarely exceeds a few centimeters. Aydin and Johnson (1978) noted that displacement along individual shear surfaces is small, being at most a few millimeters to just a few centimeters. Microscopically, the cataclastic zones of the web structure are characterized by a broken and reduced grain size are caused by comminution relative to the surrounding rocks (Pl. 4B). The shear zone of the fine grain size through cataclasis is occupied by a clayey to silt detrital matrix, and the comminuted quartz and feldspar grains lack undulatory extinction. Thus, the characteristic feature of the shear band may have caused strain hardening. Mesoscopically, they are cross-cut by the younger hybrid fracture in the Lichi Melange. Therefore, it is obvious that the crack was formed prior to the compressional shearing structures of hybrid fracture and scaly foliation.

DISCUSSION

In the terrains of the convergent plate boundary, the horizontal compression should exceed the vertical loading. However, on the landward side of an accretionary prism, gravitational loading may exceed the horizontal compression so that normal hydraulic fractures can occur (Westbook and Smith, 1983). Theoretically, the layer-parallel extensional fractures may have been modified during the horizontal extension force due to strata loading (Westbook and Smith, 1983). The crack and vein, that apparently can be formed by high fluid pressure, are well developed and were reported by the Nankai accretionary prism (Knipe, 1986; Moore, 1989; Maltman *et al.*, 1993) and Kodiak Complex (Vrolijk, 1987; Sample and Moore, 1987). The crack and vein, however, have not been reported in the cores from the passive margin, but do occur in cores from all active margins (Lundberg and Moore, 1986). The present author believes that these structures reflect the tectonic deformation and stratigraphic disruption in the accretionary prism. This is a particular environment for the development of hydraulic fractures where the horizontal stresses are exceeded by the vertical ones, and where the above-referred fractures were formed before the collision. The higher shear strains in the melanges, however, resulted in the intense disruption and hydrofracturing that characterize in the accretionary prism

Plate 1



A. Lenticular inclusions of sandstone enveloped in a matrix of mudstone. The matrix is pervaded by subparallel slip surfaces which impart a shearing "scaly foliation" in the Lichi Melange, Coastal Range.

B .The Lichi Melange exposed along the Longitudinal Valley. Len shaped inclusions of relatively resistant sandstone blocks in cohesive, strongly sheared shale matrix.

Plate 2

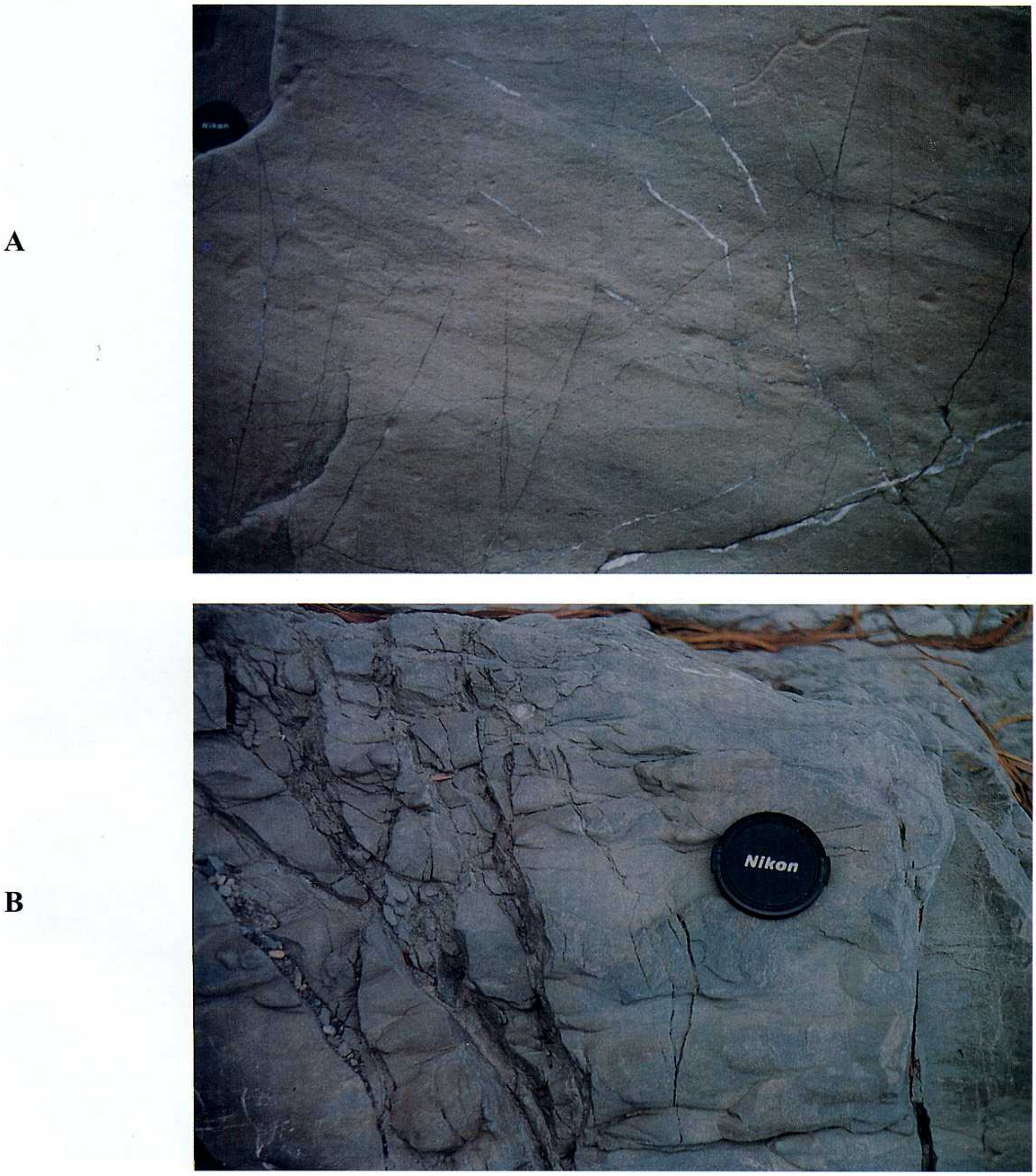
A

B

A. Features of blocks include signoidal boudinage, high-angle normal fault (extensional shear feature) and bedding-plane shear. The offsets indicate normal fault movement which occurs perpendicular to both the long and intermediate axes of the sandstone blocks.

B. Example of the well-developed extensional fractures that are commonly present in the sandstone blocks.

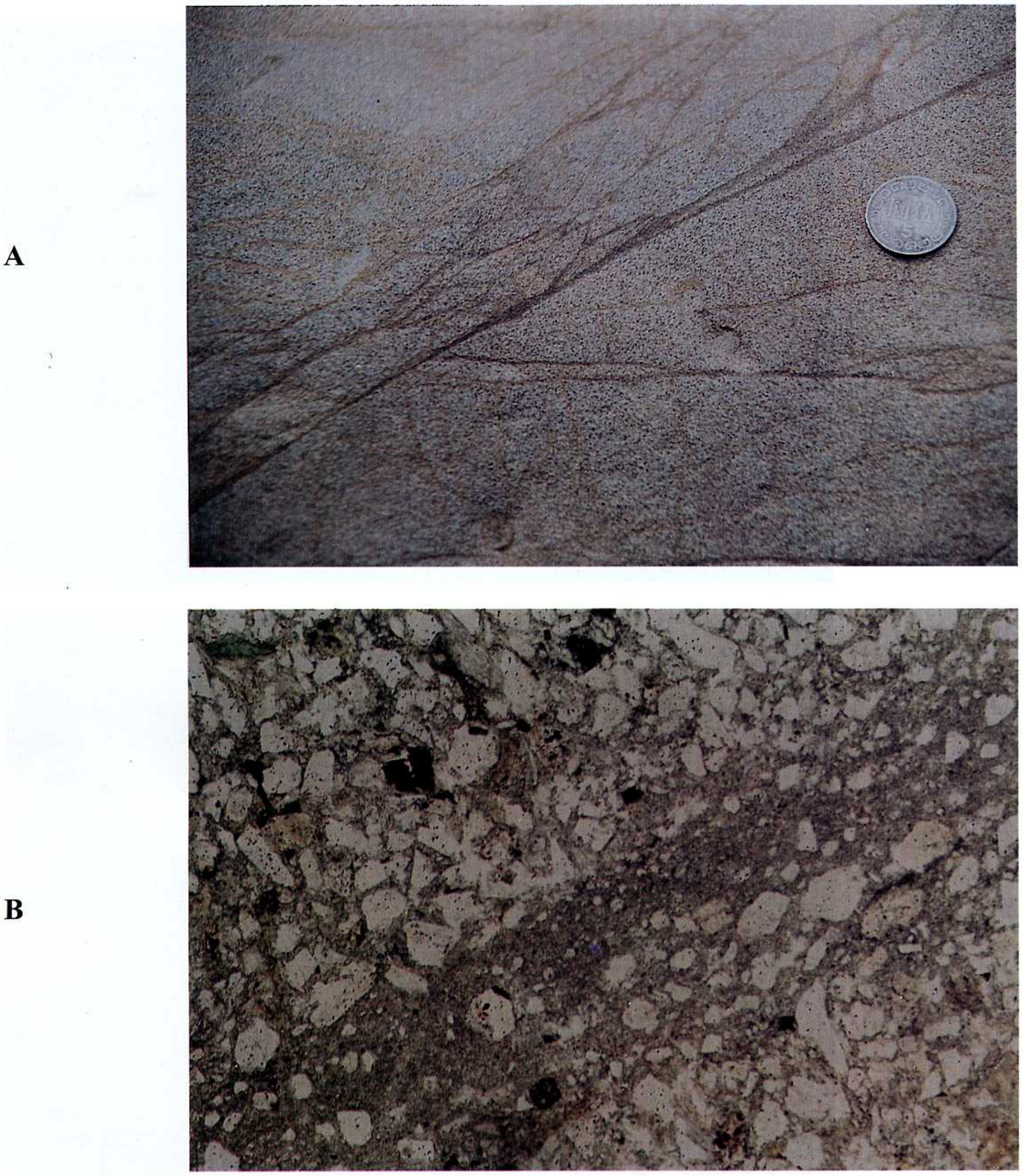
Plate 3



A. Most prominent fractures developed as conjugate sets of extension cracks. The calcite veins occur as the infilling of the extensional fractures in sandstone boudins.

B. Fracture boundary is irregular and the crack tapers down-/upward to the bedding plane. The extensional fractures appear to be annealed.

Plate 4



A. Cataclastic shear zone (web structure) cross-cutting sandstone block from the Lichi Melange.

B. Photomicrograph of a cataclastic shear zone in a quartzwacke sandstone block from the Lichi Melange. The shear zone is marked by the grayish color and the abrupt reduction in the average grain size.

Fig. 3

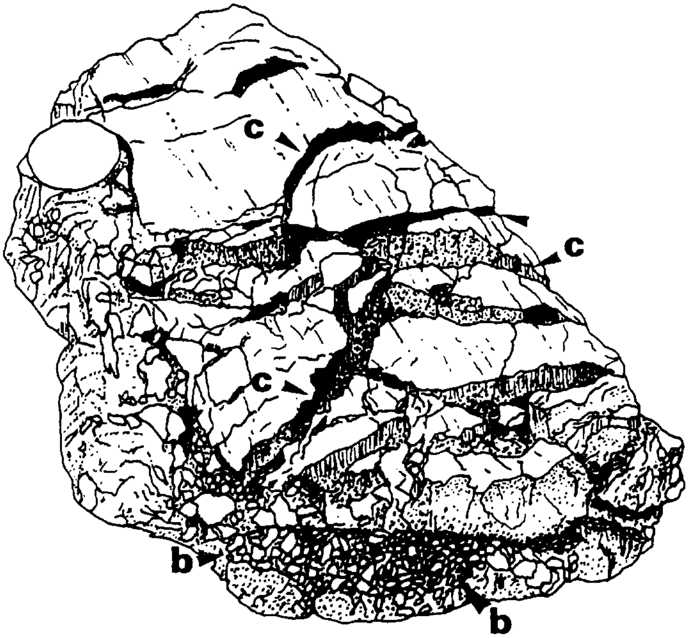
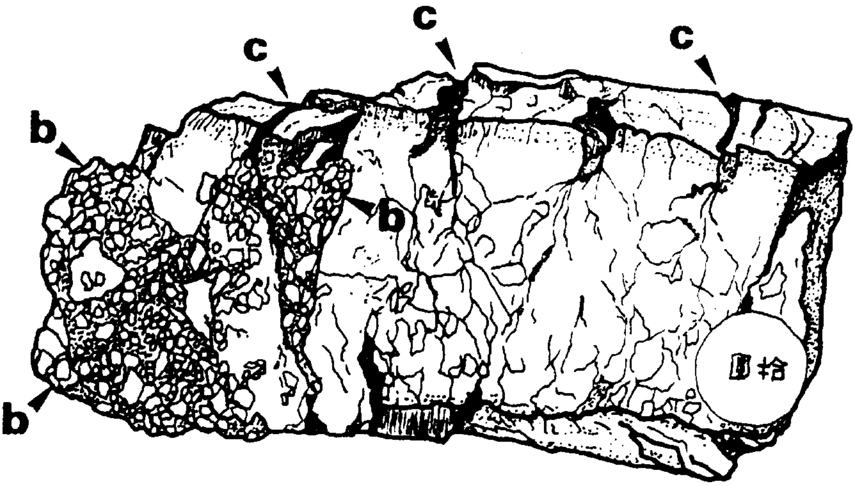


Fig. 4



Figures 3, 4. Sketch of the sandstone block from the Lichi Melange. Note the extensional fractures and breccias on the V-shape of the extension cracks are regularly spaced fractures of the order of 2 centimeters to a few millimeters in width. C: extension cracks, B: sandstone breccias.

(Fisher and Byrne, 1987; Moore *et al.*,1995; Brown *et al.*, 1994). The extension crack and vein in the sandstone blocks in the Lichi Melange represent an intense hydrofracture that occurred in the coherent strata beneath or above the shear zone in the accretionary prism (Fig. 5a).

The cataclastic fractures can be found in the accretionary wedge of the Japan Trench (Knipe, 1986) and Middle America Trench (Lundberg and Moore, 1986). In these areas, the web structures were developed at burial depths of about 250-1,000 m. Therefore, the formation of the web structure must have been due to faulting rather than gravity sliding (Lundberg and Moore, 1986). Similar structures have also been recognized in sandstone clasts in the ancient melange of the Uyak, Franciscan melange (Cowan, 1982) and the Gundahl Complex (Moore and Allwardt, 1980;Fergusson, 1984) and appear to be common features in many melange complexes. Byrne (1984) suggested that web structures reflect the tectonic deformation and stratigraphic disruption in a typical melange complex. Accordingly, the web structure represents a layer-parallel compression or shearing associated with initial accretionary processes(Fig. 5a).

The intensively scaly foliation with its consistent orientation in the Lichi Melange occurs throughout the matrix. The pervasive foliation demonstrates a large shortening perpendicular to the foliated planes. The shortening was accomplished by a left-lateral strike-slip movement that is the same as the Longitudinal Valley strike-slip fault (Fig. 5b). The Lichi Melange forms a northeast elongated belt within the eastern side of the Longitudinal Valley. Theoretically, the strongest shearing should have first occurred in the accretionary prism during subduction. Therefore, the striations in the scaly foliation in the Lichi Melange should incline at a high angle and exhibit a thrust-type movement. However, the author could not find this type of striation in foliation in the Lichi Melange. Perhaps, the most primary scaly foliation in a localized sheared zone was modified and reset by the left lateral strike-slip movement after the collision process. This accounts for the fact that the N10°-30°E trending, and steeply dipping foliation with a striation plunge of 0°-20° to the north or south is dominant.

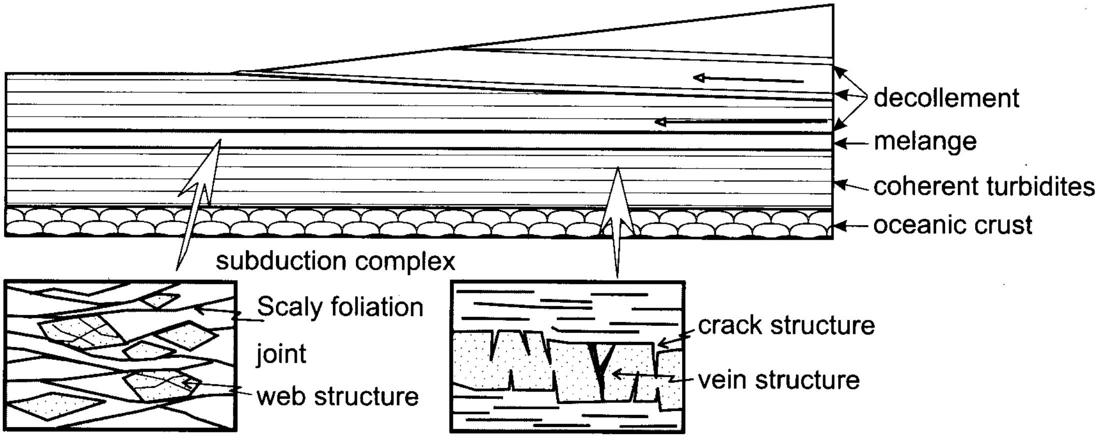
CONCLUSIONS

The melange represents an underthrusted sedimentary pile that was tectonically deformed and dewatered in the accretionary prism (Fisher and Byrne, 1987). The deformation involves particulate flow, and the development of the web structure and scaly foliation in the Lichi Melange (Fig. 5a). The melange is characterized by four dominant structures: scaly foliation, hybrid fracture, extension fracture (crack) and cataclastic shear fracture (web structure).

The web structures and crack are commonly observed in sandstone blocks and exhibit some degree of lithification and healing. The orientations of these structures are not consistent with the orientation scaly foliation in the matrix and are cross-cut by younger hybrid fractures. This suggests that the crack was originally restricted to specific strata of the confined high-pressure zone. Besides, the web structure has accommodated pervasive layer-parallel shearing that may have occurred in the underthrust zone in the accretionary prism. The crack and web structures represent the early stages of development of fabrics found in ancient subduction complexes.

Melanges are commonly interpreted as being representative of exposed remnants of ancient subduction zones. The Lichi Melange also represents an ancient subduction complex. In addition to the common features mentioned above, structural observations show that the Lichi Melange has been further modified by the strike slip shearing due to the oblique arc-continent collision.

5a.Stage 1 (Miocene)



5b.Stage 2 (Early Pliocene-Pleistocene)

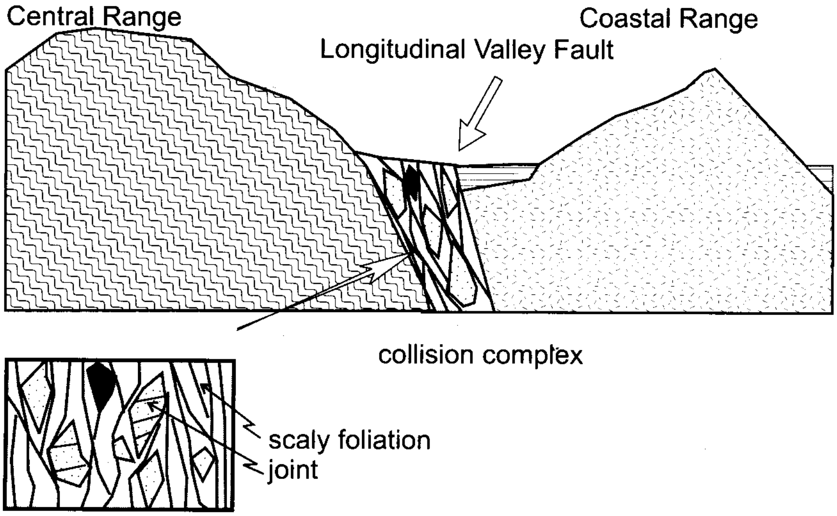


Figure 5. a. Interpretation of the structure occurrence of an underthrust sediments in a convergent margin (after Fisher and Byrne, 1977; Byrne and Fisher, 1990). b. Schematic cross-section in eastern Taiwan showing structure occurrence of the collision complex in the Longitudinal Valley Fault.

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REFERENCES

Aydin, A. and Johnson, A.M. (1978) Development of faults as zones of deformation bands and as slip surfaces in sandstone: *Pure Applied Geophysics*, **116**, 931-942.

Barrier, E. and Muller, C. (1984) New observations and discussion on the origin and age of the Lichi Melange: *Mem. Geol. Soc. China*, **6**, 303-326.

Barrier, E. and Angellier, J. (1986) Active collision in eastern Taiwan, the Coastal Range: *Mem. Geol. Soc. China*, **7**, 79-106.

Biq, Chingchang (1971) Comparison of melange tectonic in Taiwan and in some other mountain belts: *Petrol. Geol. Taiwan*, **9**, 79-106.

Brown, K.M., Bekins, B., Clennell, B., Dewhurst, D. and Westbook, G. (1994) Heterogeneous hydrofracture development and accretionary fault dynamics: *Geology*, **22**, 259-262.

Byrne, T. (1984) Early deformation in melange terranes of the Ghost Rocks Formation, Kodiak Islands, Alaska. In: Melanges: their nature, origin, and significance: *Geol. Soc. Am. Spec. Paper 198*, ed. Raymond, L.A., 21-52.

Carson, C. and Berglund, P.L. (1986) Sediment deformation and dewatering under horizontal compression: Experimental results. In: Structural fabric in Deep Sea Drilling Project Cores from forearc: *Geol. Soc. Am. Mem.*, ed. Moore, L.C., **166**, 135-150.

Chai, B.H.T. (1972) Structure and tectonic evolution of Taiwan: *Am. J. Sci.*, **272**, 669-682.

Chang, L.S. (1967) A biostratigraphic study of the Tertiary in the Coastal Range, eastern Taiwan, based on smaller foraminifera. (I. Southern Part): *Proc. Geol. Soc. China*, **10**, 64-76.

Chen, W.S. (1988) Tectonic evolution of sedimentary basins in the Coastal Range, eastern Taiwan: unpubl. Ph.D., thesis, Nat'l Taiwan Univ., Taipei, Taiwan, 304pp.

Chen, W.S. (1991) Origin of the Lichi Melange in the Coastal Range, eastern Taiwan: Spec. *Publ. Cent. Geol. Surv.*, **5**, 257-266.

Chen, W.S. and Wang, Y. (1988) The Plio-Pleistocene basin development in the Coastal Range of Taiwan: *Acta Geol. Taiwanica*, **26**, 37-56.

Chen, W.S., Chen, J.S., Wang, Y. and Huang, T.Y. (1990) Stratigraphy of the Coastal Range, eastern Taiwan: *Cent. Geol. Sur. Spec. Publ.*, **4**, 239-260.

Chen, W.S. and Lin, Y.C. (1992) Origin of the Lichi Melange in the Coastal Range, eastern Taiwan: *AGU 1992 Fall Meeting abstract*, 540pp.

Chi, W.R., Namson, J. and Suppe, J. (1981) Record of plate interactions in the Coastal Range, eastern Taiwan: *Mem. Geol. Soc. China*, **4**, 155-194.

Chung, S.L. and Sun, S.S. (1992) A new genetic model for the East Taiwan Ophiolite and its implications for Dupal domains in the Northern Hemisphere: *Earth Planet. Sci. Lett.*, **109**, 133-145.

Cowan, D.S. (1974) Deformation and metamorphism of the Franciscan subduction zone complex northwest of Pacheco Pass, California: *Geol. Soc. Am. Bull.*, **85**, 1623-1634.

Cowan, D.S. (1982) Deformation of partly dewatered and consolidated Franciscan sediments near Piedras Blancas Point, California. In: Trench-forearc geology: *Geol. Soc. London Spec. Publ.*, ed. Leggett, J.K., **10**, 439-457.

Dorsey, R.J. (1988) Provenance evolution and unroofing history of a modern arc-continent collision: evidence from petrography of Plio-Pleistocene sandstones, eastern Taiwan: *J. Sed. Petrol.*, **58(2)**, 208-218.

Dorsey, R,J. and Lundberg, N. (1988) Lithofacies analysis and basin reconstruction of the Plio-Pleistocene collision basin, Coastal Range of eastern Taiwan: *Acta Geol. Taiwanica*, **26**, 57-132.

Dorsey, R.J. (1992) Collapse of the Luzon Volcanic arc during onset of arc-continent collision: evidence from a Miocene-Pliocene uncomformity, eastern Taiwan: *Tectonics*, **11(2)**, 177-191.

Ernst, W.G. (1977) Olistostromes and included ophiolitic debris from the Coastal Range of Eastern Taiwan: *Mem. Geol. Soc. China*, **2**, 97-114.

Fergusson, C.L. (1984) The Gundahl Complex of the New England Fold Belt, eastern Australia: a tectonic melange formed in a Paleozoic subduction complex: *J. Struct. Geology*, **6(3)**, 257-271.

Fisher, D. and Byrne, T. (1987) Structural evolution of underthrusted sediments, Kodiak Islands, Alaska: *Tectonic*, **6(6)**, 775-793.

Greenly, E. (1919) The geology of Angelsey, Great Britain: *Geol. Surv. Mem.*, 980pp.

Ho, C.S. (1977) Melange in the Neogene sequence of Taiwan: *Mem. Geol. Soc. China*, **2**, 85-96.

Ho, C.S. (1982) *Tectonic evolution of Taiwan*: Ministry of Economic Affairs, Taipei, Taiwan, Roc, 126pp.

Hsu, K.J. (1971) Franciscan melange as a model for eugeosynclinal sedimentation and underthrusting tectonics: *J. Geol. Res.*, **76**, 1162-1170.

Hsu, K.J. (1974) Melanges and their distribution from olistostromes. In: Modern and ancient geosynclinal sedimentation: *Soc. Economic Paleont. Mineral. Spec. Publ.*, ed. Dott, R.H., Jr. and Shver, R.H., **19**, 321-333.

Hsu, K.J. (1988) Melange and the melange tectonics of Taiwan: *Proc. Geol. Soc. China*, **31(2)**, 87-92.

Hsu, T.L.(1956)Geology of the Coastal Range, eastern Taiwan: *Bull. Geol. Surv. Taiwan*, **8**, 39-63.

Huang, T.Y. (1969) Some planktonic foraminifera from a bore at Shihshan, near Taitung, Taiwan: *Proc. Geol. Soc. China*, **12**, 103-119.

Karig, D.E. (1973) Plate convergence between the Philippine and Ryukyu Islands: *Mar. Geol.*, **14**, 377-389.

Knipe, R.J. (1986) Microstructural evolution of vein arrays preserved in Deep Sea Drilling Project cores from the Japan Trench, Leg 57: *Mem. Geol. Soc. Am.*, **166**, 75-87.

Liou, J .G., Jahn, B.M. and Yen, T.P. (1976) Petrology of East Ophiolites: *Petrol. Geol. Taiwan*, **13**, 59-82.

Liou, J.G., Suppe, J. and Ernst, W.G. (1977) Conglomerates and pebbly mudstones in the Lichi Melange, eastern Taiwan: *Mem. Geol. Soc. China*, **2**, 115-128.

Lundberg, N. and Moore, J.C. (1986) Macroscopic structural features in Deep Sea Drilling Project cores from forearc regions: in. Moore, L. C. (ed.), Structural fabric in Deep Sea Drilling Project Cores from forearc: *Mem. Geol. Soc. Am.*, **166**, 13-44.

Lucas, S.E. and Moore, J.C. (1986) Cataclastic deformation in accretionary wedges: Deep Sea Drilling Project Leg 66, southern Mexico, and on-land examples from Barbados accretionary wedge (Deep Sea Drilling Project Leg 78A): *Mem. Geol. Soc. Am.*, **166**, 89-103.

Maltman, A.J., Byrne, T., Karig, D.E. and Lallemant, S. (1993) Deformation at the toe an active accretionary prism: symposium of results from ODP Leg 131, Nankai, SW Japan: *J. Struct. Geol.*, **15(8)**, 949-964.

Moore, J.C. (1989) Tectonic and hydrogeology of accretionary prisms: role of the decollement zone: *J. Struct. Geol.*, **11, 1/2**, 95-106.

Moore, J.C. and Allwardt, A. (1980) Progressive deformation of a Tertiary trench slope, Kodiak Islands, Alaska: *J. Geophy. Res.*, **85**, 4741-4756.

Moore, J.C., Roeske, S., Lundberg, N., Shoonmaker, J., Cowan, D.S., Gonzales, E. and Lucas, S.E. (1986) Scaly fabrics from Deep Sea Drilling Project cores from forearcs. In: Structural fabric in Deep Sea Drilling Project Cores from forearc: *Geol. Soc. Am. Mem.*, ed. Moore, L.C., **166**, 55-73.

Moore, J.C., Shipley, T.H., Goldberg, D., Ogawa, Y., Filice, F., Fisher, A., Jurado, M.-J., Moore, G.F., Rabaute, A., Yin, H., Zwart, G., Bruckmann, W., Henry, P., Ashi, J., Blum, P., Meyer, A., Housen, B., Kastner, M., Labaume, P., Laier, T., Leitch, E.C., Maltman, A.J., Peacock, S., Steiger, T.H., Tobin, H.J., Underwood, M.B., Xu, Y. and Zheng, Y. (1995) Abnormal fluid pressures and fault-zone dilation in the Babados accretionary presm: Evidence from logging while drilling: *Geology*, **23(7)**, 605-608.

Page, B.M. (1978) Franciscan melanges compared with olistostromes of Taiwan and Italy: *Tectonophys.*, **47, 3/4**, 223-246.

Page, B.M. and Suppe, J. (1981) The Pliocene Lichi Melange of Taiwan: its plate tectonic and olistostromal origin: *Am. J. Sci.*, **281**, 193-227.

Pelletier, B. and Stephan, J.E. (1986) Middle Miocene obduction and late Miocene beginning of collision registered in the Hengchun Peninsula, Geodynamic implications for the evolution of Taiwan: *Tectonophys.*, **125**, 133-160.

Raymond, L.A. (1975) Tectonite and melange-A distinction: *Geology*, **3**, 7-9.

Raymond, L.A. (1984) Classification of Melange. In: Melange: their nature, origin, and significance: *Geol. Soc. Am. Spec. Paper 198*, ed. Raymond, L.A., 1-5.

Sample, J.C. and Moore, J.C. (1987) Structural style and kinematics of an underplated slate belt, Kodiak and adjacent islands, Alaska: *Geol. Soc. Am. Bull.*, **99**, 7-20.

Schoonmaker, J. (1986) Clay mineralogy and diagenesis of sediment from deformation zones in the Barbados accretionary wedge (Deep Sea Drilling Project Leg 78A). In: Structural fabric in Deep Sea Drilling Project Cores from forearc: *Geol. Soc. Am. Mem.*, ed. Moore, J.C., **166**, 105-115.

Song, S.R. and Lo. H.J. (1988) Andesites and related rocks of the Coastal Range, eastern Taiwan: *Symp. on the Arc-continent Collision and Orogenic Sedimentation in eastern Taiwan and Ancient Analogs, Field Guidebook*, 5-1--5-25.

Suppe, J., Liou, J.G. and Ernst, W.G. (1981) Paleogeographic origin of the Miocene East Taiwan Ophiolite: *Am. J. Sci.*, **281**, 228-246.

Taira, A., Okada, H., Whitaker, J. and Smith, A. (1982) The Shimanto Belt of Japan: Cretaceous-lower Miocene active-margin sedimentation. In: Trench-forearc geology: sedimentation and tectonics on modern and ancient active plate margins: *Geol. Soc. London Spec. Publ.*, ed. Leggett, J.K., **10**, 5-26.

Teng, L.S. (1980) On the origin and tectonic significance of the Lichi Formation, northern Coastal Range, eastern Taiwan: *Ti-Chih*, **2**, 51-62. (in Chinese)

Teng, L.S. and Wang, Y. (1981) Island arc system of the Coastal Range, eastern Taiwan: *Proc. Geol. Soc. China*, **24**, 99-112.

Teng, L.S. and Lo, H.J. (1985) Sedimentary sequences in the island arc settings of the Coastal Range, eastern Taiwan: *Acta Geol. Taiwanica*, **23**, 77-98.

Vrolijk, P. (1987) Tectonically driven fluid flow in the Kodiak accretionary complex, Alaska: *Geology*, **15**, 466-469.

Wang, C.S. (1976) The Lichi Formation of the Coastal Range and arc-continent collision in eastern Taiwan: *Bull. Geol. Surv. Taiwan*, **25**, 73-86.

Westbook, G.K. and Smith, M.J. (1983) Long decollements and mud volcanoes: evidence from the Barbados Ridge Complex for the of high pore-fluid pressure in the development of an accretionary complex: *Geology*, **11**, 279-283.

Yen, T.P. (1958a) Basic and ultrabasic rocks in the southwestern part of the Coastal Range, eastern Taiwan: *Taiwan Mining Industry*, **10**, 1-2, 49-58.

Yen, T.P. (1958b) Basic and ultrabasic rocks from Jihchu, Kuanshan, eastern Taiwan: *Taiwan Mining Industry*, **10(4)**, 5-8.

弧陸碰撞過程中利吉層的構造型態

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摘要

利吉混同層是由充滿鱗片狀片理結構的灰黑色泥岩所構成，此構造特造徵是經由隱沒與碰撞作用所造成，因此利吉層是屬於一種構造性質的隱沒—碰撞雜岩體。

混同層中基質泥受強烈的剪切作用而在片理面上產生許多的擦痕與條痕。全區的片理面上條痕呈一定向的方位為左向平移，片理方向大致為北偏東10°—30°、傾角向東約70°—90°；由上述的方向得知利吉混同層曾受一左向平移的剪切力所作用。另一包夾在基質泥中的岩塊因受到不同形態的外力作用而於岩塊中產生多種型態的構造如剪切性伸張構造、伸張構造與網狀結構。岩塊的長軸方向與片理面上的條痕方位相似，顯然岩塊與基質泥的受同一剪切作用。從野外產狀與構造關係來看，岩塊中的剪切性伸張構造與片理構造是受到同一的剪切作用，為一同期的構造產物。作者認為此構造是於後期碰撞過程中於碰撞帶中受到強烈的剪切作用所造成。

伸張構造產於厚層的砂岩岩塊中，呈一正斷層構造，斷層面與砂岩岩塊的層面呈一高角度相交，但與片理面無特定方向關係。伸張構造常呈V型的張裂，裂隙中或層面之上常有碎裂的角礫岩，且裂隙中常有方解石脈；上述的結構目前皆已膠結固化，因此本文認為此構造的形成與上述的剪切作用沒有關係，且形成於片理與剪切性伸張構造之前。

網狀結構是剪切作用所形成的一種網狀線紋構造，其常出現於厚層的砂岩岩塊之中，於顯微鏡下可見紋中石英顆粒呈壓碎構造，顯然受一剪切作用所造成。網狀結構與上述的片理面無方向性且線紋皆已膠結良好，顯然為一形成於片理與剪切性伸張構造之前的結構。本文認為伸張構造與網狀結構可能是隱沒作用時期位於增積岩體中剪切帶與部份岩層產生高壓帶中的構造產物。

關鍵詞：利吉混同層、弧陸碰撞