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ORIGIN OF CLASTIC DIKES IN THE COASTAL RANGE, EASTERN TAIWAN WITH IMPLICATIONS FOR SEDIMENTARY PROCESSES DURING THE ARC-CONTINENT COLLISION

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ABSTRACT

A group of vertical clastic dikes has recently been found in the volcanic blocks at Chichi in the Coastal Range, eastern Taiwan. These dikes pinch out upwards and show a thickness variation from 10 to 30 centimeters. The dike rocks consist essentially of quartz, feldspar and lithic fragments, all being similar to those constituents of the sandstones in the Paliwan Formation. The volcanic blocks are considered slide blocks, produced through the block glide of the Tuluanshan volcanics. The clastic dikes are accordingly interpreted as the products of the upward injection of unconsolidated sediments into the volcanic blocks due to liquefaction caused by an abrupt increase in pore-fluid pressure in the sediments induced by the block glide of the volcanics during the deposition of the Paliwan Formation. The slide volcanic blocks ranging from several centimeters to hundreds of meters in size are widely distributed in the Coastal Range. It is believed that the block glide of the volcanic rocks and the slumping of sediments were very common in the Coastal Range during the arc-continent collision.

Key words: clastic dike, block glide, Tuluanshan Formation, Paliwan Formation

INTRODUCTION

In orogenic belts, stratigraphic sequences can provide important information concerning not only sedimentary processes but also geotectonic evolution. Indeed, the thick pile of the sedimentary sequence in the Coastal Range, eastern Taiwan affords a good sample for these studies in the course of the collision between the northern Luzon arc and the Asian continent.

Clastic dikes are tabular-shaped bodies of clastic sedimentary rocks, generally but not always sandstones(Strauch, 1966; Peterson, 1968, 1971). They are considered to have been

formed by injection of sediments into fractures of a rock from below (Marschalko, 1978). The injection can be produced by liquefaction of unconsolidated sediments induced probably by strong earthquakes or by other means (Pickering, 1984; Davenport and Ringrose, 1987). Sandstone dikes have been reported from widely scattered localities throughout the world, but this is the first study in Taiwan to ever describe the clastic dikes found at Chichi in the Coastal Range of eastern Taiwan.

In the Coastal Range, the rocks in the stratigraphic sequence were emplaced from the early Miocene to Pleistocene. They have been grouped from the lower to the upper into the Chimei Igneous Complex, Tuluanshan Formation, Fansuliao Formation, Paliwan Formation and the Pinanshan Conglomerate (Chen, 1988; Chen and Wang, 1988a, 1988b; Teng, 1982; Teng *et al.*, 1988; Song, 1990; Song and Lo, 1988a, 1988b). However, in some localities, the volcanic rocks which have been regarded as a part of the Tuluanshan Formation overlie the shales of the Paliwan Formation and such a reverse sequence has been interpreted as the thrust fault relationship (Hsu, 1956; Ho, 1986). Another geological event which is worthy of notice is that these consist of many local unconformities in the upper part of the Tuluanshan Formation; they have generally been speculated as the consequence of some tectonic events (Yen and Lin, 1989; Dorsey, 1988,1992; Dorsey and Lundberg, 1988; Lundberg and Dorsey, 1990).

In this paper, for the first time the authors report the clastic dikes in the Coastal Range, eastern Taiwan, and based on detailed field and petrographic observations, the origin of the clastic dikes is suggested. The authors also re-evaluate the thrust fault and tectonic event explanation mentioned-above and propose a new interpretation on the reverse relationship and unconformities between the volcanic rocks and the younger sedimentary rocks.

GEOTECTONIC BACKGROUND

The Coastal Range of eastern Taiwan has been regarded as a late Cenozoic island arc adhering to the Asian continental margin through oblique collision (Figure 1) (Chai, 1972; Biq, 1981; Tsai, 1978; Bowin *et al.*, 1978; Teng, 1987; Barrier and Angelier, 1986). The Longitudinal Valley is a linear, narrow, seismically active stream valley that has been recognized as a part of the suture zone between the Eurasian Continent plate and the Philippine Sea plate (Hsu, 1956; Biq, 1981; Ho, 1986; Barrier and Angelier, 1986). As a result of southward-propagating collision between these two plates, the inter-arc basins were gradually uplifted.

The geology of the Coastal Range of eastern Taiwan can be mainly grouped into two categories. One is the pre-collision volcanic arc products that predominantly consist of volcanic and volcaniclastic rocks with a few fringe reef limestones. They include the Chimei Igneous Complex and the Tuluanshan Formation (Figure 2) (Hsu, 1956; Ho, 1986; Chen and Wang, 1988b; Song, 1990; Song and Lo, 1988a, 1990). The other is the syn- to post-collision deposits that are mainly composed of Taiwan-derived sediments. The stratigraphic sequence of the latter is the Fanshuliao Formation, Paliwan Formation and Pinanshan Conglomerate (Figure 2)(Teng, 1980, Teng *et al.*, 1988; Chen, 1988; Dorsey, 1992; Dorsey and Lundberg, 1988; Lundberg and Dorsey, 1990). The Lichi Melange is the subduction complex comprising the deposits ranging from the initiation of subduction to the arc-continent collision (Figure 2).

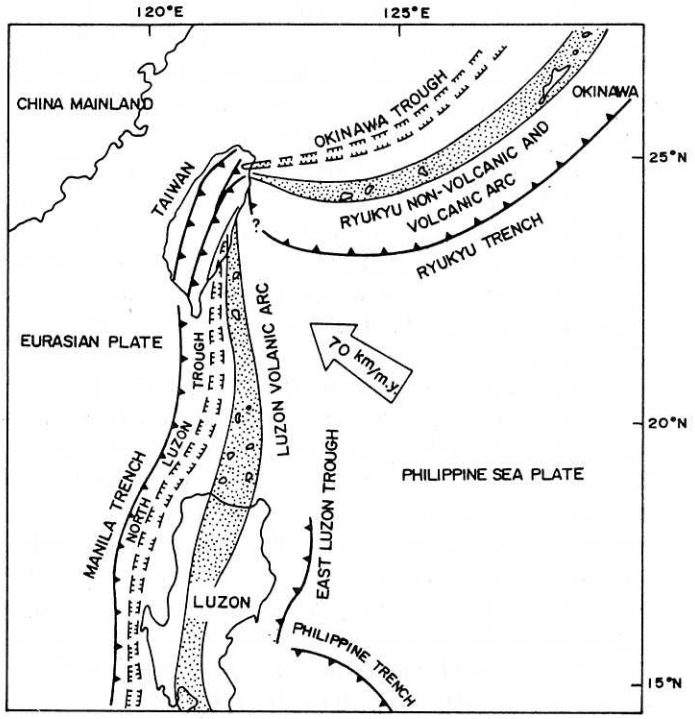
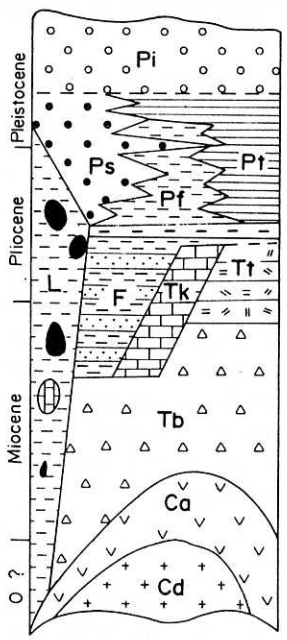


Figure 1. Tectonics in the vicinity of Taiwan (after Ho, 1986).



Pi : Pinanshan Conglomerate

Paliwan Formation

Ps : Shuilien Conglomerate

Pt : Taiyuan Member

Pf : Futien Member

F : Fanshuliao Formation

L : Lichi Formation

Tuluanshan Formation

Tk : Kangkou Limestone

Tt : Shihtiping Tuff

Tb : Shihmen Breccia

Chimei Igneous Complex

Ca : Wantian Andesite

Cd : Tienkangshan Diabase

Figure 2. The stratigraphic sequence of the Coastal Range of eastern Taiwan (Modified from Teng *et al.*, 1988; Song and Lo, 1990).

The Chimei Igneous Complex occurs as intrusives, dikes, lava flows and pyroclastics, and it may further be grouped into two members, namely, the Tienkangshan Diabase and the Wantian Andesite (Song and Lo, 1988b; Song, 1990). These rocks have suffered from at least three stages of hydrothermal alteration (Lan, 1982). Fission track and potassium-argon radiometries constrain the age of the Chimei Igneous Complex from 29.7 to 15.4 Ma (Juang and Bellon, 1984; Richard *et al.*, 1986; Yang *et al.*, 1988). The Tuluanshan Formation which includes a variety of volcanics and volcaniclastics, such as lava flows, volcanic breccias, lapillistones, tuffs, tuffaceous conglomerates along with sandstones and associated limestones, may be separated into three members: Shihmen Breccia, Shihtiping Tuff and Kangkou Limestone. The Tuluanshan Formation has been dated to 16.6-3.5 Ma by potassium-argon dating and fossils (Juang and Bellon, 1984; Chen, 1988; Song, 1990; Huang *et al.*, 1988).

The Fanshuliao Formation is composed of alternating shales and sandstones dominated by volcanic detritus, fossil remains, and quartzofeldspathic fragments (Teng, 1980; Teng *et al.*, 1988; Chen andd Wang, 1988a; Chen, 1988) and overlies the Tuluanshan Formation. The Paliwan Formation consists of intercalated conglomerates, sandstones and shales with slate and metasandstone fragments as dominant components in the conglomerates and sandstones. Due to the relative abundance of conglomerate, sandstone and shale, the Paliwan Formation may further be classified into three subunits, namely the Shuilien Conglomerate, Taiyuan Member and Futien Member (Teng *et al.*, 1988; Chen and Wang, 1988a; Chen, 1988). It overlies both the Fanshuliao and Tuluanshan Formations. The Pinanshan Conglomerate consists of layered conglomerates interbedded with sandstones and shales. Most of the lithic fragments are believed to have been derived from the Tananao Complex (Teng *et al.*, 1988; Chen, 1988).

THE CLASTIC DIKES

The Host Rock

The host rocks of the clastic dikes include volcanic breccias, tuffs and tuffaceous sandstones which are the typical rock associations of the Tuluanshan Formation. The volcanic breccias are massive, matrix-supported and white with their rock fragments being angular and ranging from 5 to 15 centimeters in diameter. Similarly, the tuffs are massive and white and fine- to coarse-grained. They are dominantly composed of glassy shards and crystals with a few rock fragments (Plate IA). Plagioclase, augite and hypersthene are the main constituents of the mineral grains. The tuffaceous sandstones are white to light-grey and are fine- to medium-grained consisting of plagioclase, pyroxene, hornblende, volcanic rock fragments and bioclastics and cement with a calcite or calcite-matrix mixture (Plate IB). The sedimentary structures of the tuffaceous sandstones are faint to massive. At least two groups of joints are well-developed in tuffs and tuffaceous sandstones. Lithologically, the host rocks of the clastic dikes can be correlated with the Shihtiping Tuff of the upper Tuluanshan Formation (Song and Lo, 1988a, 1990; Song, 1990).

Field Relationship

More than five clastic dikes crop out near No.20 bridge at Chichi in the northern Coastal Range of eastern Taiwan (Figure 3). They are generally sinuous, vertical to subvertical and wedge-shaped to lenticular and extend about 5~10 meters (Plate IIA) with their width varying

from 5 to 30 centimeters. The wedge-shaped dikes with a maximum width of 10 centimeters in the bottom pinch out at a height of 5~7 meters in the outcrops. The lenticular dikes, 3~5 meters in length with a maximum width of 30 centimeters in the middle, pinch out both ends. In fact, the exact dimensions of the clastic dikes are not clearly shown in the outcrops.

The clastic dike rocks are dark-grey and moderately to strongly indurated sandstones which closely resemble those in the Paliwan Formation. Locally, they contain a few angular to subangular tuffaceous fragments ranging from 2 to 8 centimeters. These rock fragments are identical to the host rocks in lithology and might possibly have been derived by scraping off the host rocks from the wall during the injection of the sandy sediments. The dikes are generally more competent and indurated than the host rocks and, therefore, they are more persistent against erosion. Detailed observations show that the contacts between the host rocks and the dikes are usually irregular, but the sharp and stringer-like structures always extend a few centimeters from the main lenticular dikes into the surrounding host rocks. The consistency of fracture and joint patterns between the host rocks and the clastic dikes indicates that the clastic dikes suffered from external stress after their emplacement.

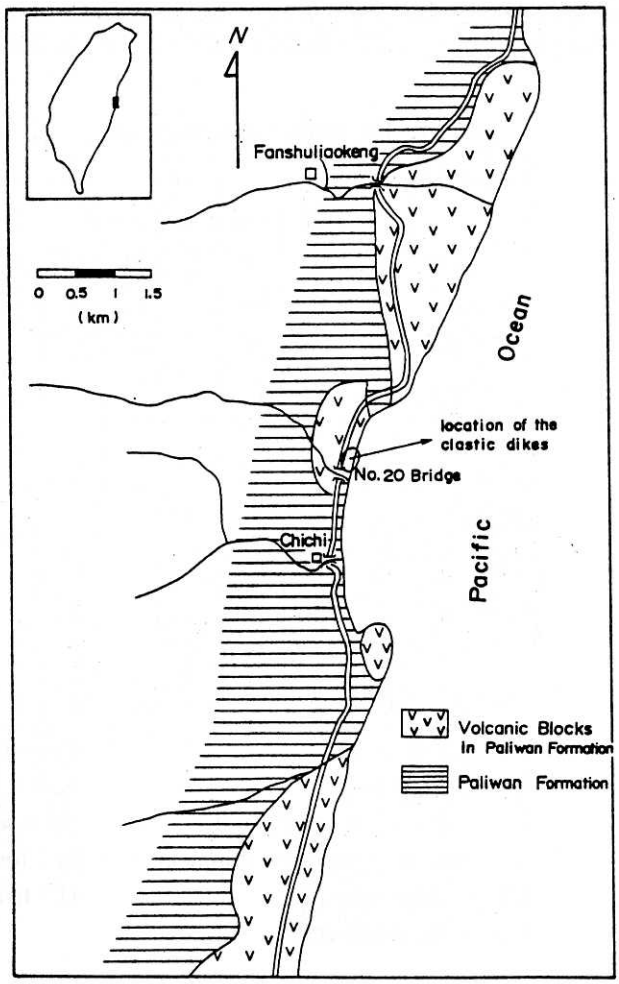


Figure 3. Geological map of the Chichi area of the Coastal Range, eastern Taiwan showing the location of the clastic dikes and the relationship between the volcanic blocks and Paliwan Formation.

Petrograpy

The clastic dike rocks are fine- to medium-grained sandstones and are dominated by quartz, carbonates and sedimentary and metamorphic rock fragments (Table 1, Plate IIB). Minor constituents include plagioclase, pyroxene and serpentine and volcanic rock fragments. Quartz is mostly medium-grained and subangular and is either monocrystalline or polycrystalline. Polycrystalline quartz with mossaic texture and polygonized boundaries are generally considered as the metamorphic origin (Blatt, 1967; Blatt and Christie, 1963). Quartz-rich siltstone and slate are the chief ingredients of the rock fragments, with the former slightly richer than the latter (Table 1). Quartz grains and siltstone rock fragments are subrounded, whereas the slate fragments are usually angular and tabular. Carbonate occurs as the principal cementing material and also as fossil remains. Basaltic rocks with laths of plagioclase are the dominant rock types in the volcanic rock fragments in addition to the minor tuffaceous chips of about 0.5 to 1 centimeter in size.

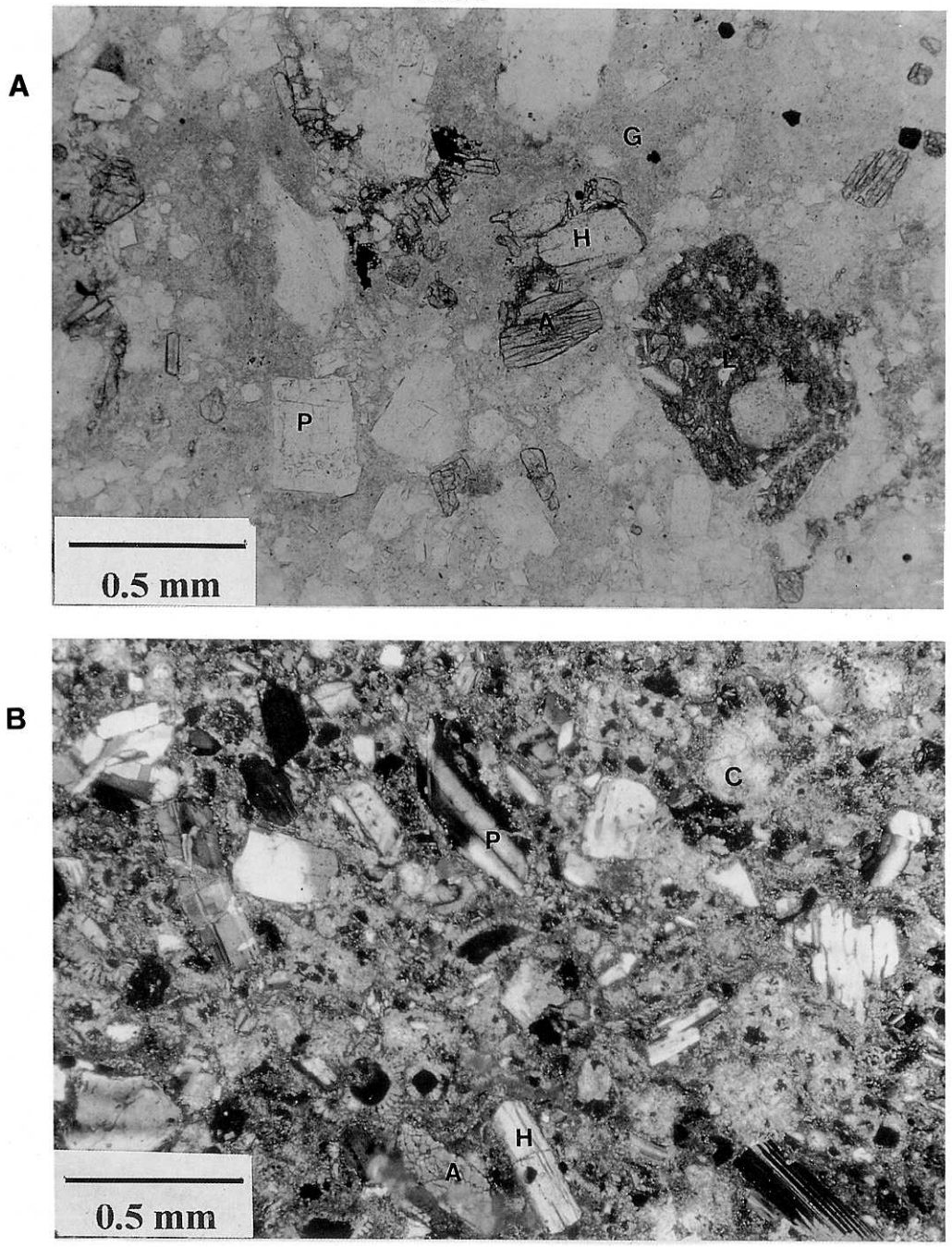
The clastic dike rocks always show a preferred orientation of the tabular grains, such as slate fragments in the contact zone (Plate IIIA). The tabular slate fragments prefer to orientate parallel to the wall of the host rocks, an orientation which may probably have formed through high pressure injection (Harms, 1965; Peterson, 1968).

Table 1. The modal compositions of the clastic dikes and the host rocks

Sample No	Type	Quartz		Feldspar		Rock Fragments			Carbonates		Opaque	Matrix
		Qp	Qm	Pl	K-F	Lv	Ls	Lm	Fs	Cm	H&Op	
LS86-139	dike	8	28	2	0	2	22	18	6	5	1	8
LS86-140	dike	6	39	3	0	2	25	13	3	4	3	2
LS93-010	dike	7	40	2	0	1	24	15	2	5	2	2
LS93-011	dike	10	32	2	0	1	18	25	0	5	3	4
LS93-012	dike	9	36	3	0	2	26	15	2	4	2	1
LS93-022	dike	12	29	2	0	0	16	28	1	4	3	5
LS93-023	dike	7	37	3	0	3	25	16	0	3	2	4
LS93-024	dike	15	31	1	0	0	12	29	1	4	2	5
LS93-008	host	0	0	33	0	42	0	0	3	10	12	0
LS93-019	host	0	0	29	0	46	0	0	2	15	8	0
LS93-020	host	0	0	37	0	45	0	0	0	0	18	0

Qp : polycrystalline quartz
Qm : monocrystalline quartz
Pl : plagioclase
K-F : potassium feldspar
Lv : volcanic rock fragment
Ls : sedimentary rock fragment
Lm : metamorphic rock fragment
Fs : fossil remains
Cm : calcite cement
H : heavy mineral
Op : opaque mineral

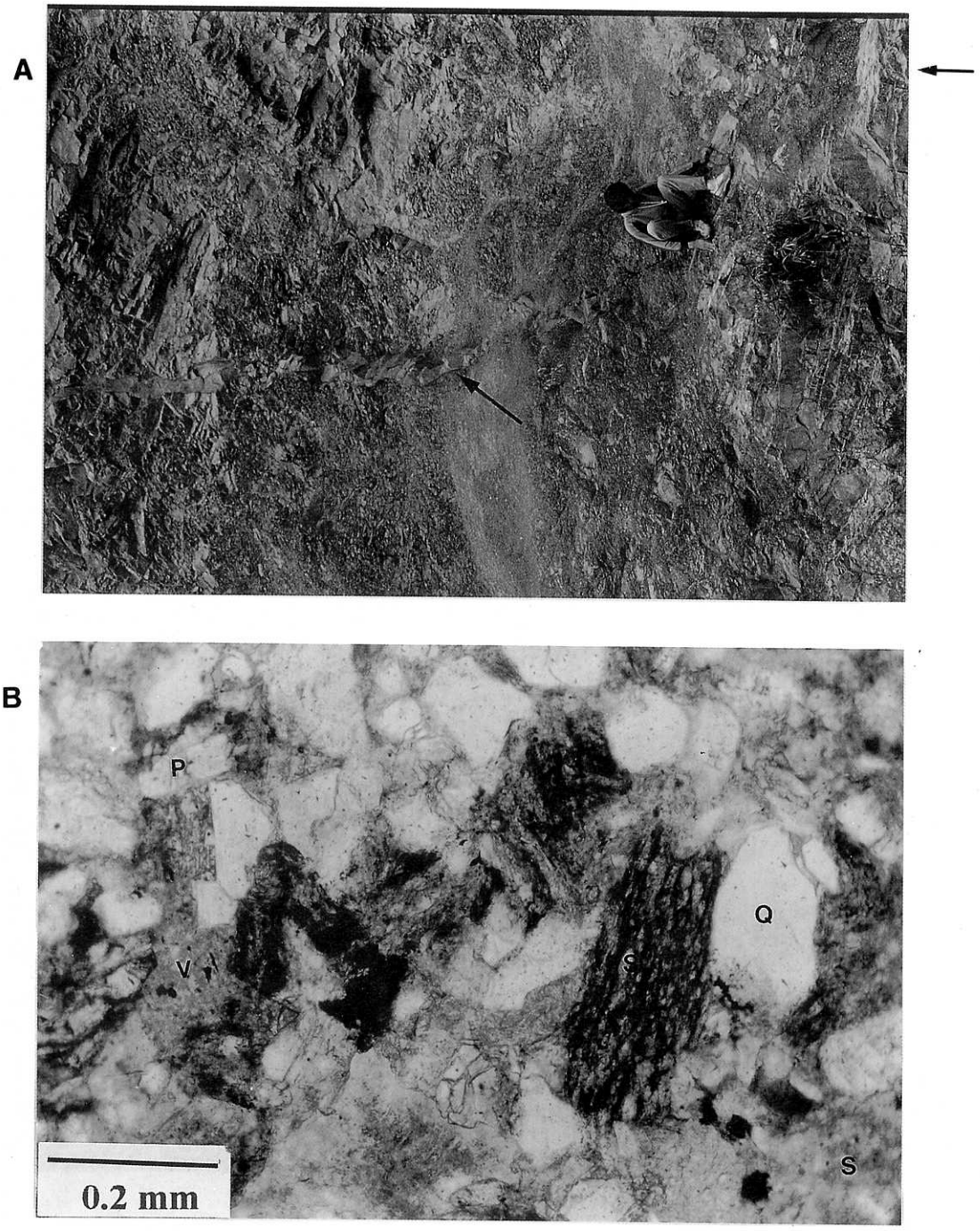
Plate I



IA: Micrograph of the host tuff; P:plagioclase; A:augite; H hypersthene; L:lithic fragment; G:glass.

IB: Micrograph of tuffaceous sandstone in host rocks; P:plagioclase; A:augite; H:hypersthene; C:calcite .

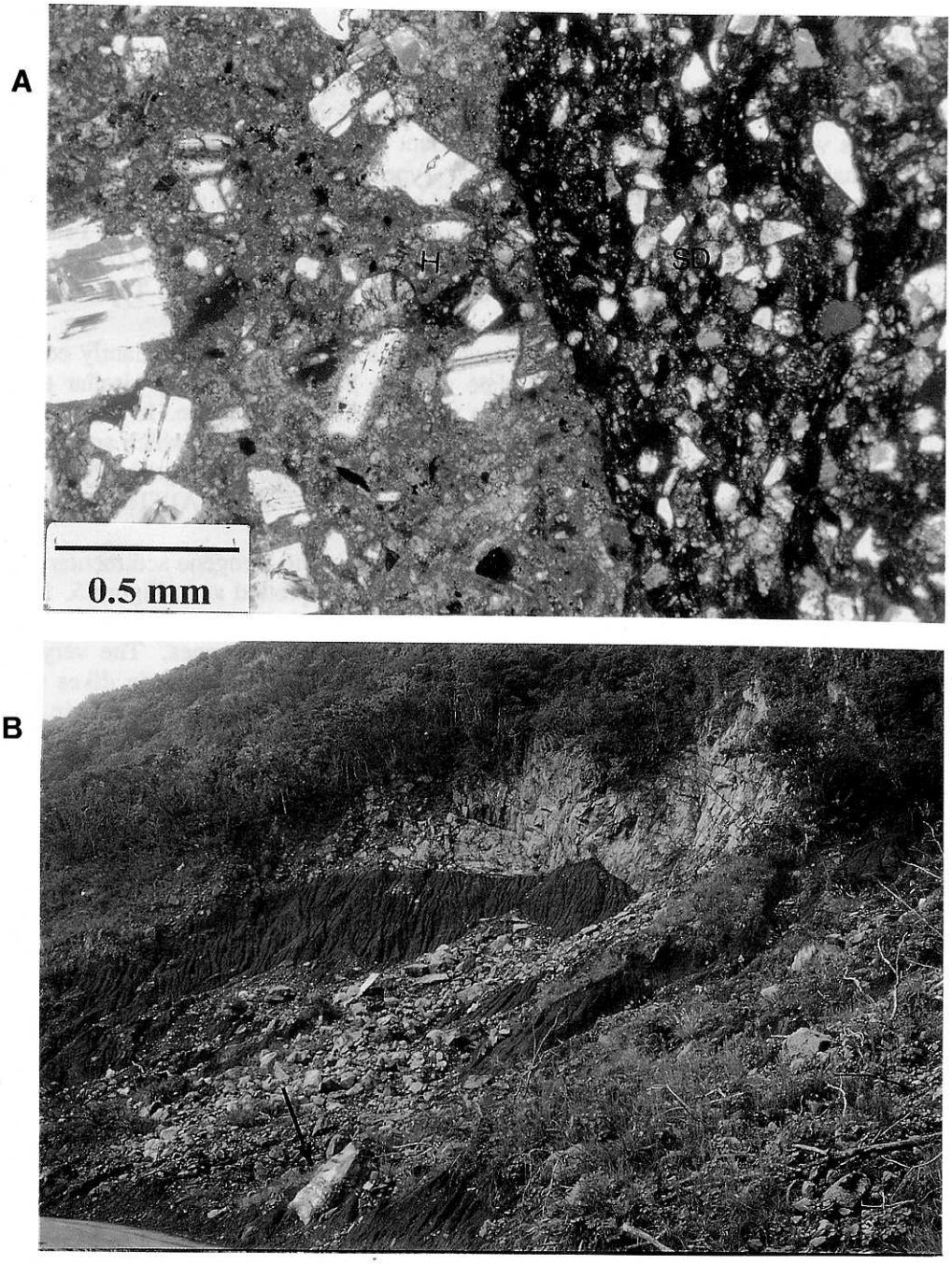
Plate II



IIA: Field occurrence of the sinuous clastic dikes in the tuffaceous block at Chichi.

IIB: Micrograph showing the main constituents, quartz (Q) and slate (SL) and sedimentary rock fragments (S) with minor volcanic fragment (V) and Plagioclase (P) of the clastic dikes.

Plate III



IIIA: Micrograph illustrating the sharp contact between the clastic dike rock (SD) and the host rocks (H) and the slate fragments oriented parallel to the contact.

IIIB: Field photograph indicating the tuffaceous slab overlying the shale of Paliwan Formation and the sharp and irregular contact between them. The arrow indicating a length of 3 meters block.

DISCUSSION

Source of the Clastic Dikes

Three types of sandstones have been distinguished in the Neogene sedimentary sequence of the Coastal Range of eastern Taiwan (Teng, 1979; Dorsey 1985; Chen, 1988). Type I is a calcareous volcaniclastic sandstone with abundant plagioclase, andesitic rock fragments and fossil remains and a minor amount of quartz. Type II is a quartz-rich subarkose with minor lithic fragments, while Type III is a graywacke that contains abundant slate fragments and little or no feldspar. The Fanshuliao Formation is predominantly composed of Type I sandstones in the north, yet Type II sandstones with minor Type I sandstones in the south(Teng, 1979; Chen, 1988). On the other hand, the Paliwan Formation is dominated by the Type III sandstones (Teng, 1979; Dorsey 1985; Chen, 1988).

The clastic dike rocks at Chichi are sandstones. They are predominantly composed of quartz and fragments of siltstone and slate and are lithologically very similar to Type III sandstones, the main sandstone constituents of the Paliwan Formation. In a Q-F-L diagram, the dike rocks are certainly fallen in the field of Type III sandstones, which are characterized by voluminous fragments of strained quartz, slate and metasandstone probably derived from the low-grade metamorphic terrain of the Asian continent (Figure 4A) (Teng, 1979; Dorsey, 1985; Chen, 1988).

In the discriminative diagrams for the sandstones in the Neogene sedimentary sequence of the Coastal Range (Chen, 1988), the clastic dikes were plotted as in Figure 5. It is clearly shown in Figure 5 that the sandstones of the clastic dikes fit fairly well into the field of the sandstones in the Paliwan Formation, especially the Pleistocene ones. The very restricted distribution of the data points indicates that the sediments of the clastic dikes were most probably supplied from the same source. It is, therefore, believed that the clastic dike rocks must have been derived from the Paliwan Formation.

The Origin of the Clastic Dikes

A clastic dike is a tabular rock body resembling an igneous dike in appearance and field relations, but it is mostly formed by an injection of mobilized sediments into a fractured, thick rock sequence from below (Peterson, 1968; Alexander, 1987). Liquefaction is generally considered the main mechanism for such injection of unconsolidated sediments and may probably be induced by large earthquakes or by other means (Diller, 1890; Davenport and Ringrose, 1987; Pickering, 1984).

On the other hand, both the injection of sediments from below (Diller, 1890) and sediments filling from above (Hams, 1965; Peterson, 1968) have been suggested for the formation of clastic dikes; however, in the latter case, the dikes are generally stratified (Lupher, 1944). The clastic dikes in the present study are believed to have been formed by the injection of sediments from below because of their pinching out upwards, the parallel arrangement of their slate fragments to the wall, and their absence of stratification of them.

Besides being caused by large earthquakes, unconsolidated sediments can be made to liquefy and flow by an abrupt increase in the pore fluid pressure through a sudden increase in a heavy loading on them owing to a large block glide. Thus, it is speculated that the clastic dikes at Chichi may have been formed by the injection of the Paliwan sediments into the fractures of the overlying volcanic blocks during their emplacement through block glides.

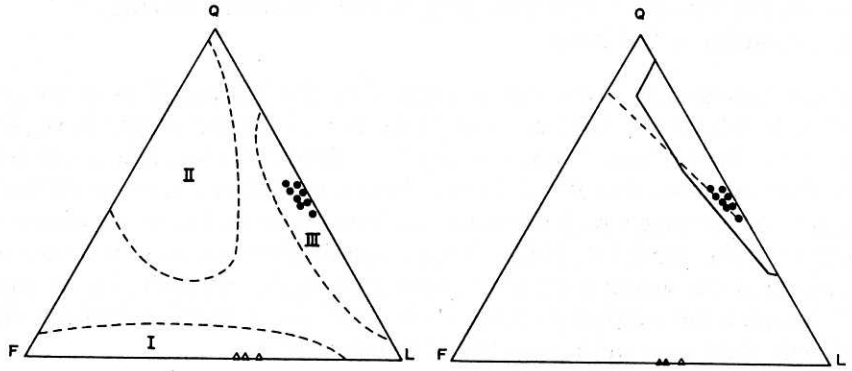


Figure 4. Q-F-L plots of the clastic dikes. (A) fields of type I, II and III sandstone defined by Teng, 1979. (B) the field of the solid line representing the sandstones of Paliwan Formation; the dash line representing the sandstones of Fanshuliao Formation (Chen, 1990). Dots denoting the clastic dikes and triangulars the host rocks.

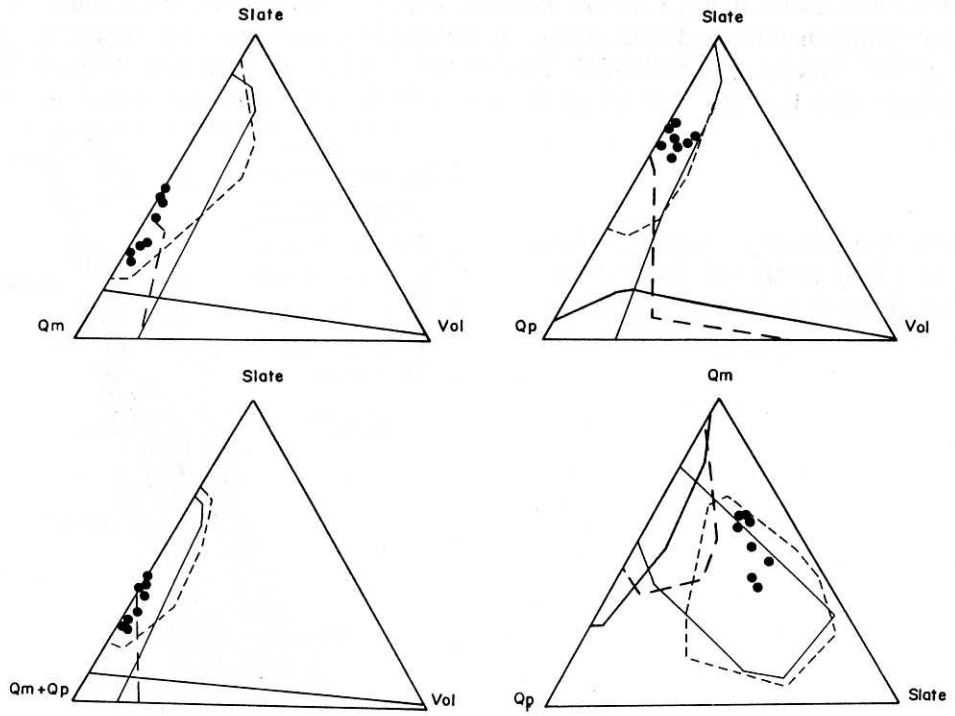


Figure 5. Plots of the clastic dike in discriminated diagrams of Chen(1988):(A) Slate-Qm-Vol; (B) Slate-Qp-Vol; (C) Slate-Qm+Qp-Vol; and (D) Qm-Qp-Slate, the field of the bold solid line representing the sandstones of Fanshuliao Formation; the solid line the sandstones of late Paliwan Formation; the bold dash line the sandstones of Lichi Formation; the dash line the sandstones of early Pleistocene Paliwan Formation.

Block Glide of the Volcanics and Slumping of the Sediments during the Arc-Continent Collision

Since the Tuluanshan Formation is older than the Paliwan Formation (Hsu, 1956; Chang, 1967a, 1967b,1968,1969; Chi *et al.*,1980, 1981;Teng and Wang, 1981; Teng and Lo, 1985;Teng *et al.*, 1988; Chen, 1988; Huang *et al.*, 1992), the volcanic rocks overlying the shale of the Paliwan Formation at Chichi have been regarded as a segment of the Tuluanshan Formation, and such a reverse rock sequence has been interpreted as an overthrust relationship by some authors (Hsu, 1956; Ho, 1986). If the volcanic slabs at Chichi were the overthrusted ones, the contact zones would have been strongly sheared. Accordingly, the sharp contacts (Plate IIIB) between the overlying volcanic slabs and the underlying Paliwan shale suggest that the volcanic slabs may most probably be the slide blocks.

A similar occurrence of slide volcanic block in the Paliwan Formation to that at Chichi is also widely distributed in other localities of the Coastal Range. They are mostly scattered in the Paliwan Formation, ranging in size from centimeters to hundreds of meters. In general, small blocks are more abundant and widely distributed than huge ones. Huge blocks are mainly distributed at Fansuliaokeng, Chichi, Antungwenchuan, Chihmenshan, Wushihpi, Sanhsientai and Yungshui, from the north to south Coastal Range (Figure 6). The slide blocks include andesitic lava flows, volcanic breccias, and tuffs, ignimbrites, tuffaceous sandstones, volcanic conglomerates and limestones. Lithologically, they are very similar to those of the Shihmen Breccia and Shihtiping Tuff of the Tuluanshan Formation (Figure 2). It is conceivable then that the Tuluanshan Formation is the most probable source for the slide blocks.

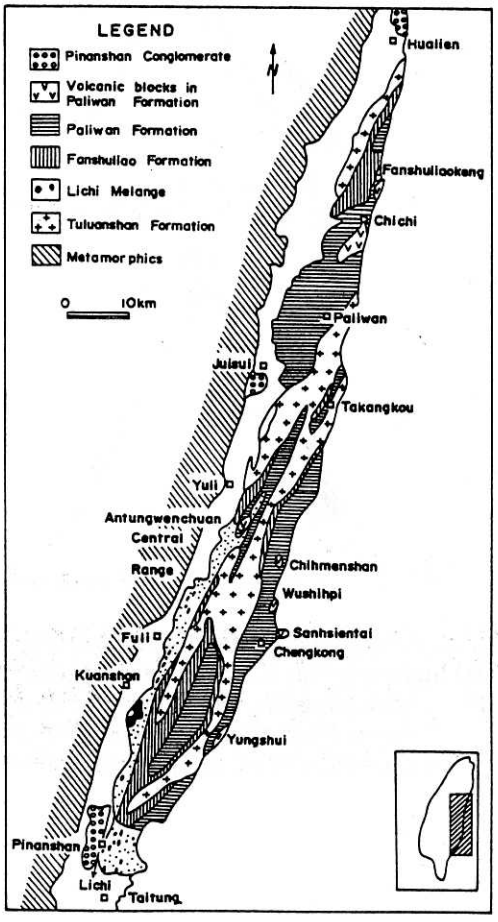
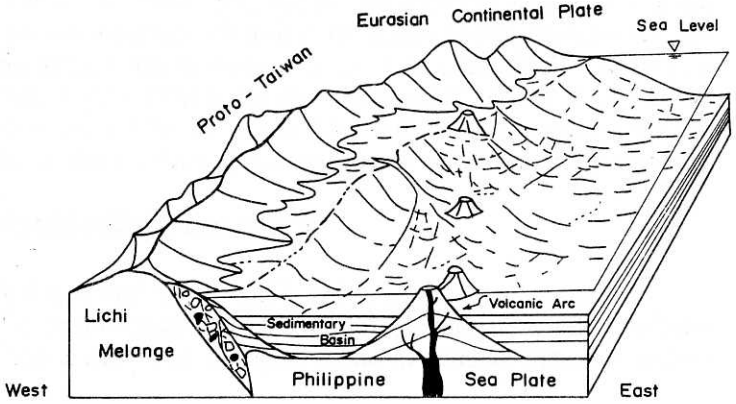


Figure 6. The geological map(after Chen, 1988; Teng,1990) and the distribution of the slide volcanic blocks in the Coastal Range, eastern Taiwan.



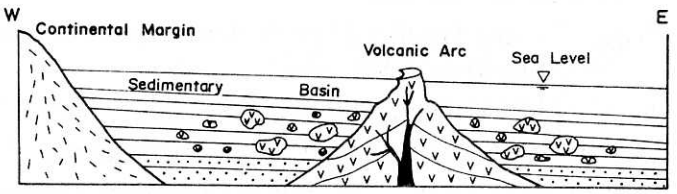


Figure 7. (A) Sketch diagram indicating the depositional environments during the arc-continent collision. (B) Cross-section showing the vertical and horizontal relationship of sedimentary basin and the volcanic arc, and distributions of the slide volcanic blocks.

Slumped structures are common in the Paliwan Formation, particularly near the contact between the Tuluanshan and Paliwan Formations; they have been considered a result of the slumping of sediments along the slope of the basin margin (Chen, 1988; Chen and Wang, 1988a; Dorsey and Lundberg, 1988). The exposure of the inner part of the volcanic edifices has been noted and attributed to the process of block glide which strips off the outer part of the volcanic edifices (Song and Lo, 1991). Accordingly, it is concluded that the slumping of sediments and block glide of the volcanic rocks were very common characteristics in the Coastal Range during the arc-continent collision (Figure 7).

Unconformities in the upper or uppermost part of the Tuluanshan Formation have been reported by many workers (Wang, 1966; Yen, 1983; Yen and Lin, 1989; Dorsey and Lundberg, 1988). A typical outcrop is at No. 5 bridge of Piehshi, Fuli (Figure 6), where the rocks of the Tuluanshan Formation are unconformably overlain by those of the Fansuliao Formation. In fact, a gap of 1 to 2 million-year standing before the deposition of the Fansuliao Formation has been recognized. Hence, Dorsey and Lundberg (1988) and Yen and Lin (1989) suggested that the volcanic arc must have once uplifted above sea level during the onset of the arc-continent collision.

It is emphasized here that a part of the unconformities mentioned above might have been formed owing to block glide which is also an erosion process. Undoubtedly, there had

been a time gap between the Tuluanshan volcanics and Paliwan sediments since most of the volcanic eruptions ended up before the commencement of the deposition of the Paliwan sediments. Consequently, a tectonic uplift is not a prerequisite for the unconformity. Since block glides of the Tuluanshan volcanics were very common during the deposition of the Paliwan sediments, it is believed that some of the unconformities between the Tuluanshan volcanics and the Paliwan sediments might have been caused by block glides.

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REFERENCES

Alexander, J. (1987) Syn-sedimentary and burial related deformation in the Middle Jurassic non-marine formations of the Yorkshire basin. In: *Deformation of Sediments and Sedimentary Rocks*, ed. M.E. Jones and R.M.F. Preston, Spec. Publ. Geol. Soc. London, **29**, 315-324.

Barrier, E., and Angelier J.(1986) Active collision in eastern Taiwan: the Coastal Range: *Tectonophysics*, **125**, 39-72.

Biq, C. (1981) Collision, Taiwan-style: *Mem. Geol. Soc. China*, **4**, 91-102.

Blatt, H. (1967) Original characters of clastic quartz: *J. Sed. Petrol.*, **37**, 401-424.

Blatt, H. and Christie, J.M. (1963) Undulatory extinction in quartz of igneous and metamorphic rocks and its significance in provenance studies of sedimentary rocks: *J. Sed. Petrol.*, **33**, 559-679.

Bowin, C., Lu, R.S., Lee, C.S. and Schouten, H. (1978) Plate convergence and accretion in Taiwan-Luzon region: *Am. Assoc. Petrol. Geol.*, **62**, 1645-1672.

Chai, B.H.T. (1972) Structure and tectonic evolution of Taiwan: *Am. J. Sci.*, **272**, 389-422.

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

Chang, L.S. (1967b) Tertiary biostratigraphy of Taiwan and its correlation. In: *Tertiary Correlations and Climatic Changes in the Pacific*, ed. K. Hatai, 57-65.

Chang, L.S. (1968) A biostratigraphic study of the Tertiary in the Coastal Range, eastern Taiwan, based on smaller foraminifera (II: Northern part): *Proc. Geol. Soc. China*, **11**, 19-33.

Chang, L.S. (1969) A biostratigraphic study of the Tertiary in the Coastal Range, eastern Taiwan, based on smaller foraminifera (III: middle part): *Proc. Geol. Soc. China*, **12**, 89-101.

Chen, W.S. (1988) Tectonic evolution of sedimentary basin in Coastal Range, Taiwan: Ph.D. Thesis, Nat'l. Taiwan Univ., Taiwan, 304p.

Chen, W.S. and Wang Y. (1988a) Development of deep-sea fan system in Coastal Range basin, eastern Taiwan: *Acta Geol. Taiwanica*, **26**, 37-56.

Chen, W.S. and Wang Y. (1988b) Volcaniclastic and biogenic sequence of the Tuluanshan Formation, Coastal Range, Taiwan: Symposium on the Arc-continent Collision and Orogenic Sedimentation in Eastern Taiwan and Ancient Analogs, Taipei, Field Guide, 6-1 – 6-26.

Chi, W. R., Namson, J. and Mei, W. W. (1980) Calcareous nannoplankton biostratigraphy of the Neogene sediments exposed along the Hsiukuluanchi in the Coastal Range, eastern Taiwan: *Petrol. Geol. Taiwan*, **17**, 75-87.

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

Davenport, C.A. and Ringrose, P.S.(1987) Deformation of Scottish Quaternary sequences by strong earthquake motion. In: *Deformation of Sediments and Sedimentary Rocks*, ed. M.E. Jones and R.M.F. Preston: Spec. Publ. Geol. Soc. London, **29**, 299-314.

Diller, J.S. (1890) Sandstone dikes: *Bull. Geol. Soc. Am.*, **1**, 411-442.

Dorsey, R.J. (1985) Petrography of Neogene sandstones from the Coastal Range of eastern Taiwan: response to arc-continent collision: *Petrol. Geol. Taiwan*, **21**, 187-215.

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**, 208-218.

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

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.

Harms, J.C. (1965) Sandstone dikes in relation to Laramide faults and stress distribution in the southern Front Range, Colorado: *Bull. Geol. Soc. Am.*, **76**, 981-1002.

Ho, C.S. (1986) A synthesis of geologic evolution of Taiwan: *Tectonophysics*, **125**, 1-16.

Hsu, T.L. (1956) Geology of the Coastal Range, eastern Taiwan: *Bull. Geol. Surv. Taiwan*, **8**, 39-64.

Huang, C.Y., Shyu, C.T., Lin, S.B., Lee, T.Q. and Sheu, D. (1992) Marine geology in the arc-continent collision zone off southern Taiwan: Implications for late Neogene evolution of the Coastal Range: *Marine Geology*, **107**, 183-212.

Huang, C.Y., Yuan, P.B. and Teng, L.S. (1988) Paleontology of the Kangkou Limestone in the middle Coastal Range, eastern Taiwan: *Acta Geol. Taiwanica*, **26**, 133-160.

Juang, W.S. and Bellon, H. (1984) The potassium-argon dating of andesites from Taiwan: *Proc. Geol. Soc. China*, **27**, 86-100.

Lan, C.Y. (1982) Mineralogy, petrology and hydrothermal alteration of Chimei Igneous Complex, Hualien, Taiwan: *MRSO Report*, **193**, 60p.

Lupher, R.L. (1944) Clastic dikes of the Columbia Basin region, Washington and Idaho: *Bull. Geol. Soc. Am.*, **55**, 1431-1462.

Lundberg, N. and Dorsey, R.J. (1990) Rapid Quaternary emergence, uplift, and denudation of the Coastal Range, eastern Taiwan: *Geology*, **18**, 638-641.

Marschalko, R. (1978) Clastic dikes. In: The Encyclopedia of Sedimentalogy, Ed. Fairbridge and J. Bourgeois, 125-126. Dowden, Hutchinson and Ross, Stroudsbury, Pennsylvania.

Peterson, G.L. (1968) Flow structures in sandstone dikes: *Sediment. Geology*, **2**, 177-190.

Peterson, G.L. (1971) Sandstone dikes and sills in the Moreno Shale, Panoche Hills, California: *Bull. Geol. Soc. Am.*, **82**, 3201-3208.

Pickering, K.T. (1984) The Upper Jurassic "Boulder Beds" and related deposits: a fault-controlled submarine slope, NE Scotland: *J. Geol. Soc. London*, **141**, 357-374.

Richard, M., Bellon, H., Maury, R.C., Barrier, E., and Juang, W.S. (1986) Miocene to recent calc-alkaline volcanism in eastern Taiwan: K-Ar ages and petrography: *Tectonophysics*, **125**, 87-102.

Song, S.R. (1990) Volcanology and geochemistry of volcanic rocks in the middle part of Coastal Range, eastern Taiwan, and implications for evolution of the North Luzon Arc: Ph.D. Thesis, Nat'l. Taiwan Univ., Taiwan, 251p.

Song, S.R. and Lo, H.J. (1988a) Volcanic geology of Fengpin-Takangkou area, Coastal Range of Taiwan: *Acta Geol. Taiwanica*, **26**, 223-235.

Song, S.R. and Lo, H.J. (1988b) Andesites and related rocks of the Coastal Range, eastern Taiwan: Symposium on the Arc-continent Collision and Orogenic Sedimentation in Eastern Taiwan and Ancient Analogs, Taipei, 5-1 – 5-25.

Song, S.R. and Lo, H.J. (1990) Stratigraphy of volcanics and related rocks in the Coastal Range, eastern Taiwan: *Spec. Publ. Central Geol. Survey*, **4**, 261-270.

Song, S. R. and Lo, H.J. (1991) Lithofacies variation of near-vent facies in the andesitic volcanoes: *Spec. Publ. Central Geol. Survey*, **5**, 282. (Abstract)

Strauch, F. (1966) Sedimentgange von Tjornes (Nord-Island) und ihre geologische Bedeutung: *Neues Jahrb. Geol. Palaontol.*, **124**, 259-288.

Teng, L.S. (1979) Petrographical study of the Neogene sandstones of the Coastal Range, eastern Taiwan, (I. northern part): *Acta Geol. Taiwanica*, **20**, 129-155.

Teng, L.S. (1980) Lithology and provenance of the Fanshuliao Formation, northern Coastal Range, eastern Taiwan: *Proc. Geol. Soc. China*, **23**, 118-129.

Teng, L.S. (1982) Stratigraphy and sedimentation of the Suilien Conglomerate, northern Coastal Range, eastern Taiwan: *Acta Geol. Taiwanica*, **21**, 201-220.

Teng, L.S. (1987) Tectostratigraphic facies and geological evolution of the Coastal Range, eastern Taiwan: *Mem. Geol. Soc. China*, **8**, 229-250.

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.

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., Chen, W.S., Wang, Y., Song, S.R. and Lo, H.J. (1988) Toward a comprehensive stratigraphic system of the Coastal Range, eastern Taiwan: *Acta Geol. Taiwanica*, **26**, 19-35.

Tsai, Y.B. (1978) Plate subduction and the Plio-Pleistocene orogeny in Taiwan: *Petrol. Geol. Taiwan*, **15**, 1-10.

Wang, Y. (1966) Some geologic observation in the Coastal Range, eastern Taiwan: *Proc. Geol. Soc. China*, **9**, 46-54.

Yang, T.Y., Liu, T.K. and Chen, C.H. (1988) Thermal event records of the Chimei igneous complex: constraint on the ages of magma activities and the structural implication based on fission track dating: *Acta Geol. Taiwanica*, **26**, 236-246.

Yen, T.P. (1983) Correlation of the Tertiary crustal movements between Taiwan and its western offshore: *Petrol. Geol. Taiwan*, **19**, 1-16.

Yen, T.P. and Lin, W.H. (1989) Coastal Range unconformity of Taiwan: *Petrol. Geol. Taiwan*, **25**, 1-10.

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東臺灣海岸山脈碎屑性岩脈的成因及其在弧陸碰撞沉積作用的意義

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摘要

在東臺灣海岸山脈北段的磯碕附近，至少有五條由砂岩組成的碎屑性岩脈，侵入都巒山層的凝灰岩中，其厚度從10到30公分不等，並有向上尖滅和向下變厚的趨勢。岩脈中砂岩的主要組成爲石英、長石、岩屑和板岩岩屑，是典型八里灣層砂岩的成份。在岩脈露頭的北邊，都巒山層之凝灰岩直接覆蓋在八里灣層的頁岩之上，兩者的接觸相當鮮明，接觸帶並無任何的剪動和破碎。因此，出露於磯碕附近，覆蓋在八里灣層之上的都巒山層爲一巨大之滑落岩塊，而不是由逆衝斷層所形成。砂岩岩脈是由都巒山層的巨大岩塊滑落至沉積盆地中後，因上覆岩壓突然升高，使未固結的沉積砂層液化，然後沿著都巒山層凝灰岩的裂隙侵入，而形成了砂岩岩脈。

除了磯碕以外，都巒山層火山岩的巨大岩塊滑落到八里灣層中者，從北到南有蕃薯寮坑、安通山、赤門山、烏石鼻、三仙台和湧水等地，而小的岩塊分佈更廣。岩塊的大小從數公分到數百公尺長不等，由此可知，在弧陸碰撞過程中，島弧斜坡的崩塌和巨大岩塊滑落至沉積盆地的沉積作用，是一相當普遍的現象。

關鍵詞：碎屑性岩脈，地塊滑動，都巒山層，八里灣層。