Oligocene-Miocene Bu Khang extensional gneiss dome in Vietnam: Geodynamic implications

Laurent Jolivet Département de Géotectonique, URA Tectonique, Université Pierre et Marie Curie, T 26-0 E1, case 129, 4 place Jussieu, 75252 Paris Cedex 05, France
Henri Maluski Laboratoire de Géochronologie Géochimie Pétrologie, UMR 5567, Université Montpellier II, Place Eugène Bataillon, 34095 Montpellier Cedex, France
Olivier Beyssac, Bruno Goffé – Laboratoire de Géologie, URA 1316, Ecole Normale Supérieure, 24 rue Lhomond, 75231 Paris Cedex 05, France
Claude Lepvrier Département de Géotectonique, URA Tectonique, Université Pierre et Marie Curie, T 26-0 E1, case 129, 4 place Jussieu, 75252 Paris Cedex 05, France
Phan Truong Thi National University of Hanoï, Gemtesting Laboratory, 54, Tran Nhan Tong, Hanoi, Vietnam
Nguyen Van Vuong Laboratoire de Géologie, URA 1316, Ecole Normale Supérieure, 24 rue Lhomond, 75231 Paris Cedex 05, France

ABSTRACT

A large Oligocene-Miocene extensional gneiss dome in Vietnam has implications for the kinematics of the Ailao Shan–Red River shear zone and rifting of the South China Sea. A major northeast-dipping extensional shear zone separates the Bu Khang dome from less-metamorphosed units above. Shearing deformation occurred during the exhumation of high-pressure rocks. ^{40}Ar-^{39}Ar ages on micas reveal Oligocene-Miocene ages, from 36 to 21 Ma. After a high-pressure episode of probable Oligocene age, the area was subjected to northeast-southwest extension during the opening of the South China Sea. A kinematic model involving left-lateral shear and block rotation within a north-south dextral shear zone integrates our observations in the Bu Khang dome with South China Sea rifting.

GEOLOGICAL SETTING

The internal deformation of the Indochina peninsula (Fig. 1) during the left-lateral motion along the Ailao Shan–Red River shear zone is considered as negligible (Tapponnier et al., 1986) or large (Rangin et al., 1995a). The Bu Khang dome is a large Oligocene-Miocene extensional structure situated inside the Indochina block. Its presence suggests that considerable thinning affected Indochina during the contemporaneous left-lateral motion, and it has implications for the debate about the role played by large strike-slip shear zones and extrusion tectonics. The direction of extension observed in the dome can be used to constrain a model of block rotation during the opening of the South China Sea.

Left-lateral slip during the late Oligocene–early Miocene is proven along the Ailao Shan–Red River shear zone (Leloup et al., 1995; Harrison et al., 1996). Several other left-lateral faults have been described farther south in Indochina (Rangin et al., 1995b; Roques et al., 1997) and Thailand (Lacassin et al., 1997): the Song Ca, Wang Chao, and Three Pagoda faults. A diachronism is evidenced with younger faulting toward the north, related to the northward indentation of India (Huchon et al., 1994; Lacassin et al., 1997). Various estimates of the finite left-lateral slip along the Ailao Shan–Red River shear zone (Lacassin et al., 1993; Rangin et al., 1995b; Tapponnier et al., 1986) lead to different visions of the deformation of Southeast Asia with large-scale extrusion (Briais et al., 1993; Tapponnier et al., 1982) or without extrusion (Dewey et al., 1989; Huchon et al., 1994).

The Bu Khang dome is located ~200 km south of the Ailao Shan–Red River shear zone in Vietnam (Phan, 1991). Preliminary ^{40}Ar-^{39}Ar dating of gneiss and marbles gave ages (36–21 Ma) much younger than the expected Indosinian ages (Maluski et al., 1997; Lepvrier et al., 1997a).

BU KHANG DOME

Geometry

The axis of the Bu Khang dome trends northwest-southeast and the foliation is gently folded in a broad antiform. Four units are recognized, separated by tectonic contacts parallel to the regional foliation (Fig. 2). The uppermost unit is composed of Mesozoic sediments that were poorly metamorphosed and little deformed. It overlies two units of marbles that contain metabauxite pods (Phan Truong Thi, 1980). The lowermost unit is the core of the dome. It consists of micaschists, paragneiss, and orthogneiss, as well as migmatitic veins. A conspicuous northeast-trending stretching lineation and synfolial folds is seen in all lithologies of the two marble units and the lowermost unit.

The northeast side of the dome is characterized by a northeast-dipping shear zone (Quy Chau shear zone) with consistent top-to-the-northeast kinematic indicators. A transition in space from ductile to brittle is observed from southwest to northeast toward the contact with the upper plate. The intensity of stretching decreases toward the southwest, and the consistency of kinematic indicators becomes less obvious. The southern margin of the dome shows a clear lineation but no clear evidence for noncoaxial flow. The lower marbles show the same direction of stretching and are probably within the shear zone.

The deformation history in the core of the dome can be summarized as follows: It formed

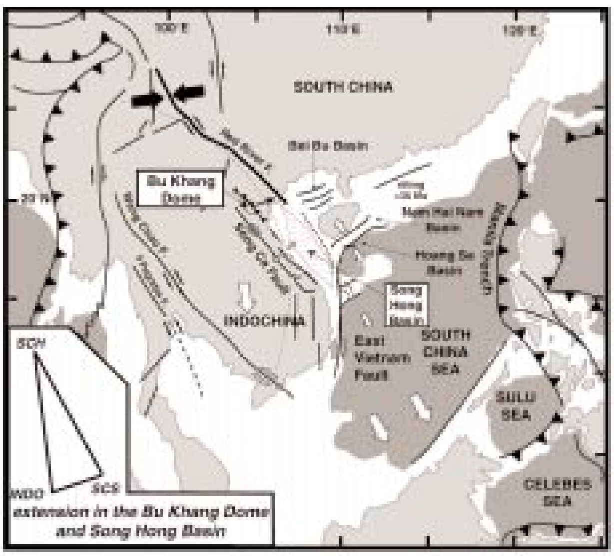

Figure 1. Tectonic map of southeast Asia and South China Sea. The Bu Khang dome and Song Hong basin are indicated south of southeast termination of Red River fault. Dotted line is small circle that fits opening of South China Sea (Briais et al., 1993). East Vietnam fault is dextral during formation of South China Sea (Roques et al., 1997; Taylor and Hayes, 1983). The velocity triangle shown in inset explains the kinematic relations between the southern margin of the South China Sea (SCS), South China (SCH) (assumed stable in this study), and Indochina (INDO).

during a northeast-southwest stretching stage and the deformation localized in the last stages along a northeast-dipping shear zone.

Pressure-Temperature (*P-T*) History

Metapelites in the center of the dome contain the following paragenesis: garnet, phengite, biotite, quartz, plagioclase. Inclusions in garnet of titanite in ilmenite and kyanite suggest that garnet formation started in the field of titanite-almandine at $P > 10$ kbar (Bohlen et al., 1983). Biotite/garnet thermometry (Ferry and Spear, 1982; McMullin et al., 1991) yields $T = 600 \pm 50$ °C and phengite-biotite-garnet barometry (Massonne, 1995; McMullin et al., 1991) gives $P = 11–12$ kbar. *P-T* calculations were performed using Ptax software and its database (Berman, 1988; Berman and Perkins, 1987). The same paragenesis is observed in the shear zone, and very abundant kyanite and late staurolite are affected by the shearing deformation. Maximum *P-T* conditions are within 550 ± 50 °C and 9–10 kbar. Metabauxites of the upper marble unit (above and north of the Quy Chau shear zone) contain diaspore, late margarite, chlorite, muscovite, and rare chloritoid. A maximum temperature can be assessed from the dehydration temperature of diaspore into corundum, which is around 400–450 °C for a pressure ranging from 3 to 10 kbar. For metabauxites of the second marble unit, on the southern limb of the dome, the presence of corundum instead of diaspore implies a temperature higher than 400–450 °C. The early paragenesis (corundum + margarite + hercynite + kyanite + zoisite + rare ilmenite) in those high-temperature metabauxites suggests a temperature higher than 670 °C at a minimum pressure around 8–9 kbar followed by cooling (destabilization of kyanite-zoizite into margarite). This first paragenesis is overprinted by a second one (corundum, margarite, chloritoid, kyanite, titanite, and ilmenite) that suggests a lower temperature, around 500 °C, for a pressure ranging from 4 to 10 kbar. The top-to-the-northeast shear is contemporaneous with the crystallization of staurolite and a final stage of chlorite and white micas. It ends in semibrittle conditions.

From this preliminary study we can draw the following conclusions: An early high-pressure stage (11–12 kbar) is observed in all samples in the micaschists and gneiss of the core, as well as in the metabauxites. A progressive retrogression toward lower pressure is seen in the micaschists and metabauxites during the top-to-the-northeast shear. The pressure gaps observed through the major contacts and the downward increase of maximum pressure are compatible with an extensional core complex bounded by a top-to-the-northeast shear zone.

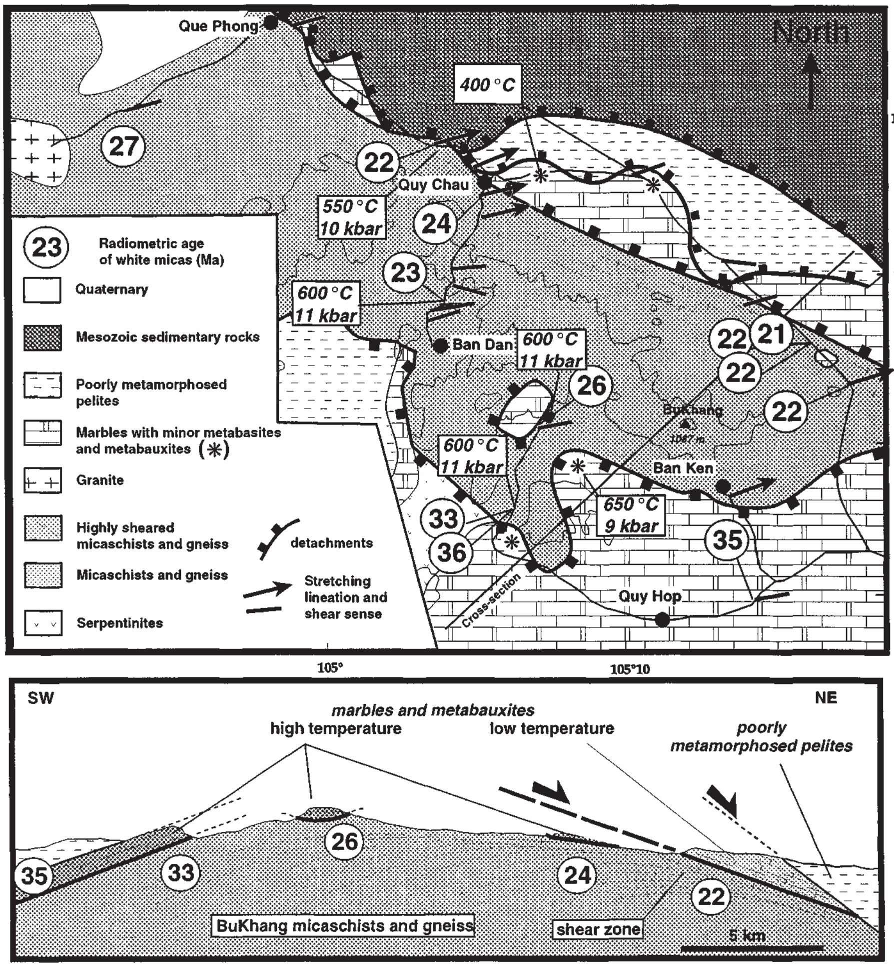

Figure 2. Tectonic map and cross section of the Bu Khang dome showing direction of stretching lineation and sense of shear. Numbers in white circles are $^{40}Ar/^{39}Ar$ radiometric dates obtained on micas. Pressure-temperature conditions are shown in white rectangles.

TABLE 1. $^{39}Ar/^{40}Ar$ ANALYTICAL DATA IN THE BU KHANG DOME

Sample number	Analyzed mineral	Plateau age (Ma)	Isochron age (Ma)	$^{40}Ar/^{36}Ar$ (Ma)	Total age (Ma)
Cover					
VN235, marble	phlogopite	35.6 ± 0.4	37.1 ± 0.3	217 ± 5	35.6 ± 0.5
VN 966, marble	muscovite	33.6 ± 0.5	33.2 ± 0.6	350 ± 7	37.1 ± 0.5
	biotite	36.1 ± 1	37.2 ± 0.9	274 ± 6	38.6 ± 0.8
Shear zone					
VN 228, foliated granite	biotite	21.4 ± 0.4	21.9 ± 0.2	312 ± 4	21.5 ± 0.5
VN 230, myl. gneiss	biotite	22.1 ± 1	21.7 ± 0.8	309 ± 5	23 ± 1
VN 231, marble	muscovite	22.4 ± 0.4	23.1 ± 0.3	233 ± 6	21.5 ± 0.6
VN 9715, myl. gneiss	muscovite	22.3 ± 0.5	21.1 ± 0.6	380 ± 0.7	22.3 ± 0.5
VN 9708, myl. gneiss	biotite	22.5 ± 0.4	22.4 ± 0.4	333 ± 5	22.6 ± 0.4
Shear zone southern limit					
VN 9709, orthogneiss	biotite	24.5 ± 0.3	24.4 ± 0.5	321 ± 4	23.6 ± 0.4
Core					
VN 9710, micaschist	muscovite	23.3 ± 0.7	22.4 ± 0.5	344 ± 5	22.4 ± 0.5
VN 9717, granite	biotite	27.3 ± 0.5	26.4 ± 0.5	386 ± 7	27 ± 0.5
VN 9705, gneiss	biotite	26.4 ± 1.1	27 ± 1	247 ± 5	27.9 ± 0.7

Radiochronology

^{40}Ar-^{39}Ar stepwise heating technique was applied on pure separated minerals from the metamorphic rocks of the gneissic core and its cover (Table 1). Analyses were performed on mineral population, using a classical high-frequency furnace. In Table 1, plateau ages (bold face) are preferred to isochron ages, because in isochron diagrams representative points are gathered close to the 39/40 intercept, which implies a poor precision for the 40/36 ratio. Figures 2 and 3 synthesize these results, which indicate a significant difference between ages from the cover (33–36 Ma), the core (23–27 Ma), and the shear zone (21–22 Ma). The oldest ages are observed in rocks of the upper and lower plates in the south. Within the core, we obtain progressively younger ages toward the northeast. All along the shear zone, ages cluster between 21 and 22 Ma. The oldest rocks thus crossed the 400 °C isotherm (closing temperature for micas) around 33–36 Ma. Progressively younger ages toward the shear zone can be interpreted as the crystallization of younger micas during the localization of strain along the extensional shear zone, which stopped at around 21–22 Ma. The major extension and exhumation of metamorphic rocks in the Bu Khang dome occurred from 36 to 21 Ma.

The Bu Khang dome is, thus, the indication of a stage of northeast-southwest extension during the late Oligocene and early Miocene in the north of the Indochina peninsula. Northwest-southeast–trending normal faults have been recognized along the northeast margin of Vietnam south of the Song Hong basin, and northeast-southwest Cenozoic extensional paleostresses were recognized onland (Lepvrier et al., 1997b; Nguyen Van Vuong, 1997). The Song Hong basin has previously been described as a left-lateral pull-apart basin (Tapponnier et al., 1982) or as a right-lateral pull-apart basin (Harder et al., 1992). The Bu Khang dome and the northeast extension recognized on land allow us to assume that the Song Hong basin opened during the same extensional stage.

BU KHANG DOME AND RED RIVER FAULT

Radiometric ages obtained from rocks along the Ailao Shan–Red River shear zone and the Bu Khang dome overlap between about 30 and 20 Ma. The northeast-southwest extensional stage was contemporaneous with the end of left-lateral slip along the Ailao Shan–Red River shear zone. We assume in the following that the dome has not been rotated more than ~15° clockwise (Yang and Besse, 1994).

A transition from transpression to transtension is recognized along the Red River fault from China to Vietnam (Leloup et al., 1995). ^{40}Ar-^{39}Ar thermochronology on feldspar from the Ailao Shan–Red River shear zone shows a diachronous exhumation (and transtension) with a clear northwestward younging (Harrison et al., 1996), 25 Ma in Vietnam to 17 Ma north of the Ailao Shan massif in China. Harrison et al. (1996) proposed that a component of northeast-southwest extension should be added to the left-lateral slip. The formation of the Quy Chau shear zone might be the consequence of the same process. High pressures recognized in the core of the dome can be obtained in the transpressional region, where crustal thickening is active. Rocks would then be exhumed once they have reached the transtensional domain.

BU KHANG DOME AND SOUTH CHINA SEA

Exhumation of metamorphic rocks in the Bu Khang dome occurred at the same time as rifting and formation of oceanic crust in the South China Sea. Recent investigations along the eastern margin of Vietnam show that the Vietnam fault (Fig. 1) was a dextral shear zone during most of the opening (Marquis et al., 1997; Roques et al., 1997; Taylor and Hayes, 1983). The direction of extension in the Bu Khang dome and presumably the Song Hong basin is not compatible with dextral motion along the Vietnam scarp. A link between rifting of the Beibu basin and left-lateral motion along the Ailao Shan–Red River shear zone can be assumed for early stages, i.e., before 30 Ma (Roques et al., 1997). We then have to explain the northeast-southwest extension that exhumed the Bu Khang dome and probably formed the Song Hong basin.

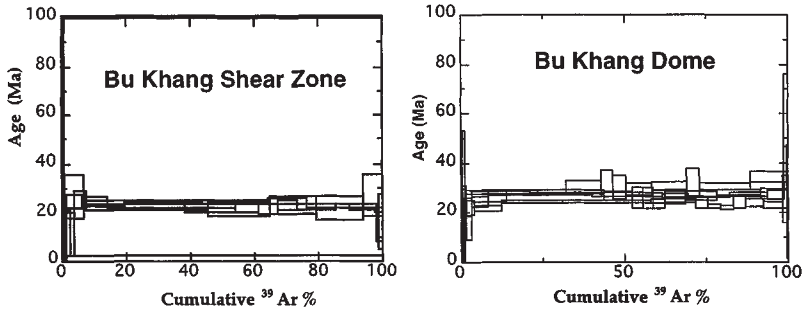

Figure 3. Synthesis of ^{40}Ar/^{39}Ar spectra in Bu Khang dome (Table 1).

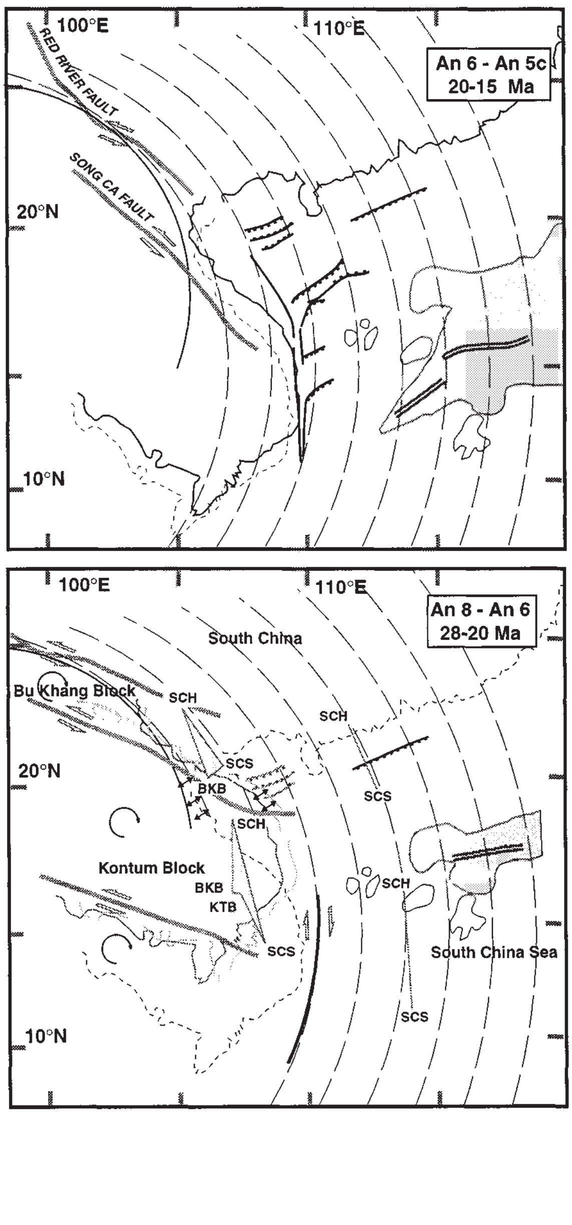

Figure 4. Kinematic model of formation of Bu Khang dome and Song Hong basin. Reconstructions of South China Sea spreading were taken from Marquis et al. (1997) and Briais et al. (1993). SCH—South China (considered fixed in this model), SCS—South China Sea southern margin, BKB—Bu Khang block, KTB—Kontum block. Dotted lines represent small circles that fit the opening direction of the South China Sea (Briais et al., 1993) and the solid line represents the rotation of the Bu Khang block. Rotation about a closer pole leads to northeast-southwest extension in the southeastern part of the block boundary.

PRELIMINARY KINEMATIC MODEL

During the late Oligocene and the early Miocene, the Song Hong basin and the Bu Khang dome were located at the junction between three blocks (Fig. 4): South China, the Indochina peninsula, and the South China Sea block (southern margin of the South China Sea). Several left-lateral faults are recognized parallel to the Ailao Shan–Red River shear zone: the Song Ca and Wang Chao faults. The South China Sea block rotated with respect to the South China block about a pole located in the Andaman Sea (Briais et al., 1993). The direction of extension across normal faults along the southeast margin of the South China block and the strike of the Red River fault roughly fit the small circles about this pole (Fig. 4), and so does the dextral Vietnam fault. The northeast-southwest extension of the Bu Khang dome and Quy Chau shear zone implies that the motion of the Bu Khang block relative to the South China block is more southerly than the motion of the South China Sea block. A simple velocity triangle shows the kinematic relations. Because there are no data that constrain the amount of finite extension, we cannot determine precisely the angle between the two directions and the velocity of the Bu Khang block. Left-lateral slip along the Song Ca fault then slightly reduces the angle between the motion of the Kontum block relative to the South China Sea block. Because of distributed extension within the continental margin, the relative velocity of the South China Sea block and the South China block increases southward. Both phenomena imply a smaller angle and a more southerly direction between the displacements of the Kontum block and the South China Sea block leading to dextral slip between the two blocks. This kinematic model is similar to a simple bookshelf mechanism involving dextrally rotating blocks within a north-south–trending shear zone that encompasses most of the Indochina peninsula (Dewey et al., 1989, Huchon et al., 1994).

CONCLUSIONS

The northwest-southeast–trending Bu Khang dome is located ~200 km south of the Red River fault. A significant crustal thinning occurred during exhumation of high-pressure metamorphic rocks. A major northeast-dipping extensional shear zone is recognized at the top of the gneiss unit. White micas reveal young ^{40}Ar-^{39}Ar ages (from 30 to 20 Ma). Ductile deformation ended about 21 Ma. A bookshelf kinematics is proposed that qualitatively accounts for the direction of extension in the Bu Khang dome and Song Hong basin. Several crustal blocks bounded by left-lateral faults (the Red River fault, the Song Ca fault, and the Wang Chao fault) rotate clockwise within a dextral shear zone. The obliquity between the motion of the Bu Khang block and South China during extension leads to northeast-southwest extension.

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