Characteristics of Blueschist in Shuangjiang Tectonic Mélange Zone, West Yunnan Province *

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ABSTRACT: Glaucohphe in Shuangjiang area, West Yunnan Province, supplies a chance for studying south segment of Lancangjiang tectonic zone. But people are at odds as to whether two-stage glaucohphe exists or not, glaucohphe is the result of dynamic metamorphism later, or indicates a high P/T metamorphic belt when Paleozoic Tethys Sea closed. Authors discover in a recent research that there is only one-stage glaucohphe in Shuangjiang area, and three blueschist belts are distributed near N-S-tending, and glaucohphe in Shuangjiang area is related to the eastward subduction of Channing-Menglian basin.

KEY WORDS: tectonic mélange zone, blueschist belt, glaucohphe.

INTRODUCTION

West Yunnan Province, located at the conjoined region between Gondwana and Yangtze block, is a collision orogenic belt due to Paleozoic Tethys Sea closed in Indo-China stage. Shuangjiang tectonic mélange zone belongs to south segment of Lancangjiang tectonic zone in Lincang-Shuangjiang area, West Yunnan Province, composed of ophiolite implicating residual oceanic crust, passive-active continental margin sediments, metamorphic basement and continental margin arc to collision-type granite, is formed by arc-land collision between Yangtze block and Yunnan-Burma-Thailand-Malaysia microcontinent, neighboring on the east edge of Gondwana land. The tectonic mélange zone westward thrust to Gengma passive continental margin, neighbors on the west edge of Channing-Menglian Paleozoic Tethys main oceanic basin. The zone borders on Simao block in the east, neighboring on the west edge of Yangtze block. The area is traditionally called Lincang-Menghai fold region, situated on the east edge of Channing-Menglian foldbelt, and is also called Chongshan-Damenglong metamorphic belt in metamorphism (Fig. 1).

The study for glaucohphe in Shuangjiang area started in 80s of the 20th century. Based on the study for glaucohphe and phengite, index high P/T metamorphic minerals, found in Neoproterozoic Lancang Group in Shuangjiang-Huijin area, researchers put forward some viewpoints as follows: ① These minerals are results of high P/T metamorphism, and originate in geological environment of block subduction (Peng and Luo, 1982; Zhou and Lin, 1982). ② Lan-
cang Group underwent Paleozoic and Pre-paleozoic two-stage metamorphism and the glaucophane is the result of dynamic metamorphism overlapped later (Geology & Mineral Resources Department of Yunnan Province, 1990; Xue and Xiong, 1989). According to Zhao and Zhong (1994a, b) and Zhao (1993), high P/T metamorphic rock in Shuangjiang-Suhi area can be divided into west belt and east belt by Zhong (1998), and he indicated that west belt, distributed in Xiaohejiang and Ankang area, underwent two-stage regional high P/T metamorphism and overlapped by third-stage retrogressive metamorphism. Glaucophane is generated in the first stage (279 Ma); the second stage regional high P/T metamorphism is related to deformational-metamorphic event due to collision and compression between continental blocks (214 Ma); the third is retrogressive and laps over the former (111 Ma). The glaucophane in the east belt, situated in Suhi area, underwent two-stage metamorphism at least, and the date of 409 Ma in glaucophane implies early subduction-collision event before Paleozoic Tethys period, the date of 215 Ma suggests that the deformational-metamorphic event is due to metamorphic basement reactivation and is drifted into collision event.

The glaucophane mainly occurs in Neoproterozoic Lancang Group in this area. Previous researchers already have been aware of glaucophane forming in geological environment of block subduction, but they still suggest that glaucophane is related to dynamic metamorphism overlapping, because it was unacceptable to determine a suture zone in Lancang Group, considered as an integrated and normal stratigraphic unit. Lancang Group was considered as reactivated metamorphic basement in the following studies, and researchers indicated that glaucophane underwent two-stage subduction-collision event in Paleozoic and Pre-paleozoic Tethys period respectively, dating glaucophane by isotopic chronology, studying glaucophane combined with Tethys Sea forming and closing. These results observably advance research level to high P/T metamorphism in West Yunnan Province. However, some sharper problems still exist, physical and tectonic environment originated glaucophane, an index high P/T, is very rigorous. So whether glaucophane, having undergone two subduction-collision events, occurs in same specimen or not regional tectonic feature and microstructure do not authenticate two-stage glaucophane existing in this area, Lancang Group, a tectonic-stratigraphic unit, which has been drifted into ductile shear zone and showed dynamic metamorphic features, is not an integrated and normal stratigraphic unit.

So far, three blueschist belts have been determined in Shuangjiang tectonic mélangé zone, they have different high P/T mineral assemblages, and occur in different ductile shear zones, and display different deformational characteristics in structural level. Structural features and mineral rings of glaucophane reflect the tectonic process of subduction-exhumation.

**TECTORIC CHARACTERISTICS**

Shuangjiang tectonic mélangé zone is moved in dextral strike-slip by Nantinghe fault zone in Mengsa area, it is rapidly narrowed in further north, and is integrated in the north segment of Lancangjiang fault zone. In Shangyun area, it is moved in sinistral strike-slip by Heihe fault, and maybe extends to Burma along Huimin-Xiding in further south. But it is

![Figure 1. Regional sketch of Shuangjiang tectonic mélangé zone.](image-url)
not as full as that in Shuangjiang area, because Lincang granite batholith intruded in the east of the mélange zone, and Mesozoic age red beds covered in the west (Fig. 1).

Regional Tectonic Characteristics

Shuangjiang tectonic mélange zone consists of Carboniferous Niujingshan ophiolite structural mélange belt, An kang thrust-nappe belt and Lincang pre-continental arc-collision granite belt (Fig. 2). These belts are divided by ductile shear zone, Carboniferous Niujingshan ophiolite structural mélange belt, implying residual oceanic crust, mainly comprises ultramafic rock, schistous amphibolite, layered amphibolite, greenschist, meta-basalt and a fewer plagioclase granite dike, layered tonalite etc. Consequently, some fragments of Permian Laba Formation, Neoproterozoic Lancang Group and Middle Proterozoic Damenglong Group are also drifted in the mélange belt. All components, showing shear structural lens and included in brittle-ductile shear zone, fit together a shear-lens tectonic system due to strong strain belt alternating with weak strain region. A plenty of igneous accumulated bandings were discovered in layered amphibolite. Meta-basalt can be correlated with MORB in geochemical characteristics, An kang thrust-nappe belt, including Late Paleozoic passive-active continental margin sediments (Devonian-Carboniferous Nanduan Formation, Permian Laba Formation) and Neoproterozoic Lancang Group, neighbors on the east edge of Niujingshan ophiolite structural mélange belt. All stratigraphical units in this belt were drifted to ductile shear zone and underwent dynamic metamorphism. Lincang pre-continental arc to collision granite belt is contact with the east edge of An kang thrust-nappe belt. It is consisted of four parts, metamorphic basement Middle Proterozoic Damenglong Group, Late Paleozoic ophiolite mélange, Permian precontinental arc granodiorite undergoing ductile shear dynamic metamorphism, and Triassic collision granite (Fig. 2).

Shuangjiang tectonic mélange zone, as regional tectonics as, basically goes through four tectonic events. The first deformation shows layered ductile shear. The tectonism, reconstructing Late Paleozoic passive-active continental margin sediments, Carboniferous Niujingshan ophiolite mélange and precontinental Neoproterozoic Lancang Group, is related to Changning-Menglian oceanic basin's eastward subduction in Late Carboniferous to Early Triassic. As a result, above stratigraphical units suffer ductile shear dynamic metamorphism, including famous high P/T metamorphism in this area. The second overlapping deformation occurs in Middle to Late Triassic and is related to collision-rogenesis. Layered ductile shear zone is drifted to thrust-nappe belt, and exhumates to surface from middle-shallow structural level. Shuangjiang tectonic mélange zone's main framework is established in this deformation. The mélange zone, a shear-lens tectonic system by strong strain belt alternating with weak strain region, reveals fan back-thrust structural style in section, namely frontal thrust-nappe westward moving and back thrust-nappe eastward. Neoproterozoic Lancang Group is overlapped by low greenschist facies metamorphism, but other stratigraphical units are exceptional. The third deformation is extension of basin-range transition. Post-collision magmatism is very violent, forming a
Jurassic basic-medium-acid volcanic zone along Lancangjiang fault zone. But overlapping structural feature is infrequent. The fourth deformation is also characterized by brittle thrust-nappe, overlapping previous structural feature. It is result of intracontinental orogenesis in Paleogene to Neogene. So, Shuangjiang tectonic mélangé zone actually preserves overlapping three deformational generations, undergoing above four tectonic events.

**Tectonic Characteristics of Blueschist Belts**

There are three blueschist belts in Shuangjiang tectonic mélangé zone. Damangguangfang blueschist belt is distributed in Niujiangshan ophiolite mélangé zone, and glaucophane determined in meta-basalt, Suyi blueschist belt and Nanlang blueschist belt both occur in Ankang thrust-nappe belt in N-S-tending, blueschist is discovered in Neoproterozoic Lancang Group (Fig. 2).

**Suyi blueschist belt**

Suyi blueschist belt is distributed in Suyi ductile shear zone along Shuangjiang to Suyi. It includes the west belt and the east belt divided by Zhong (1998), which have only been covered by Middle Jurassic Huakaizuo Formation in the border. This study finds that they are merged in Suyi blueschist belt.

The first deformational generation in Suyi ductile shear zone is layered ductile shear zone, constituted by structural schistosity. Structural schistosity (D1S1) consists of cleavage plane, mainly orientation mica, and gneiss that granular mineral concentrated. Cleavage plane netlike encircles gneiss that displays obvious shear feature. Crush porphyroclastic includes lengthened quartz, lens constituted by granular mineral. D1S1 schistosity, a penetrative foliation in all scale, demonstrates a large-scale transversal structure transposition. The foliation basically parallels to boundary between stratigraphic units. The second deformational generation is still characterized by thrusting nappe and folding D1S1 schistosity, D1f2 fold and thrusting brittle-ductile shear zone compose schuppen structure system. D2f2 fold shows I c-type and II -type and displays two occurrences, inclined plunging fold and steep-plunging to vertical fold. Crenulation cleavage grows along axial plane, attended by small-scale ductile shear zone. Brittle-ductile shear zone comprises D2S2 crenulation cleavage zone and hook-shaped fold zone and small fold zone. According to D2f2 fold occurrence and kinematic features, the second deformational generation is mainly characterized by thrust-nappe, combining with strike-slip-lateral extension. The fourth deformational generation, overlapping structure, is also thrust-nappe, moving to east, folding D2S2 foliation and forming open fold and brittle thrusting fault, leading D2 inclined west thrust-nappe paratransversal.

There are two glaucophane-bearing petrographic categories in Suyi ductile shear zone. One is metamorphic minerals of basic igneous rock (or called chlorite glaucophane-schist), and the other is meta-volcanic sediment (or called mica-quartz glaucophane-schist), they often accompany each other (Fig. 3).

Chlorite glaucophane-schist spread in Suyi ductile shear zone in different scale lenses, with big ones reaching $n \times 100 - 1000$ m in length and $n \times 10 - 100$ m in width, yet small ones can only be observed in specimen. The bigger chlorite glaucophane-schist lens is contacted with matrix by ductile shear zone; the boundary is clear and sudden. The smaller lens is contacted with matrix by second foliation, the boundary is clear too (Fig. 3). Mica-quartz glaucophane-schist, only accounted for the fewness in muscovite-quartz schist and attended by chlorite glaucophane-schist, unevenly disperses in matrix, Neoproterozoic Lancang Group; the boundary commonly is transitional.

In bigger lens, deformational partitioning is very intense. Smaller-scale ductile shear zone partitions the lens and shape shear-lens structural system, strong strain belt alternating with weak strain region (Fig. 4). The system is the result of overlapped deformation of D1 and D2 generation. Ductile shear zone of two generations can be observed in strong strain belt, the first exhibits dense flow cleavage (D1S1) zone and the second crenulation cleavage (D2S2), they basically parallel to each other. It is not easy to discriminate two-stage ductile shear zones when they basically parallel to each other or crenulation cleavage (D2S2) does not grow.

D1 generation ductile shear zone demonstrates D1S1 structural schistosity zone, fibrous-columnar and squamaceous chlorite orients and deforms foliation in microscope, some small glaucophane, epidote and albite lenses are encircled in, and shows typical shear cleavage. Deformational intensity is degraded near lens weak strain region, structural schisosity in ductile shear zone principally consists of orientation glaucophane, containing columnar epidote, albite and...
lens of assemblage that squamaceous chlorite and micas concentrated.

Lens weak strain region, containing sixty percent glaucophane, is commonly occupied by mica-albite-epidote-glaucophane schist. Orientation fibrous-columnar glaucophane forms netlike continuous cleavage. Small lens epidote, assemblage of albite and muscovite are encircled by orientation glaucophane (Fig. 5a).

Glaucophane schist contains residual idiomorphic to half-idiomorphic augite porphyritic crystal (d = 2–3 mm), rim of glaucophane and aegirine-augite around augite porphyritic crystal or crystal’s crack, and actinolite altered along glaucophane’s split (Fig. 5b). Weak strain matrix evenly comprises fine fibrous glaucophane and squamaceous chlorite, forming D₁ continuous cleavage. But in strong strain zone, flow cleavage is chiefly constituted by orientation squamaceous chlorite and micro-crystal actinolite. Residual augite displays ring texture; its core is half-idiomorphic augite, coronal rim of aegirine-augite and glaucophane and actinolite wrap augite core in succession (Fig. 5c). So, generational relationship of metamorphic mineral is clear, forming order as follows: augite → aegirine-augite → glaucophane → actinolite, logging an increasing pressure in low temperature → increasing temperature decreasing pressure metamorphic course.

D₁ generation ductile shear zone discontinuously grows, putting up D₂S₁ crenulation cleavage zone and striated fining zone. The fining zone, less than 3 mm in width, consists of alternate striation that strong orientation fibrous glaucophane and squamaceous chlorite concentrate respectively. Residual fine lens glaucophane, chlorite and albite can be discriminated in fibrous glaucophane striation. Thus it can be certified that overlapping metamorphism does not occur in glaucophane fining course. In gleitbrett of D₁S₁ crenulation cleavage, continuous cleavage comprised orientation glaucophane is folded (D₁f₁), D₁S₁ foliation is dragged to D₂S₂ crenulation cleavage (Fig. 5d), mineral assemblage is basically uniform in two-stage foliation. By the other words, glaucophanes discovered in D₁S₁ foliation and D₂S₂ crenulation cleavage belong to the same generation, glaucophane in D₂S₂ crenulation cleavage is namely previous glaucophane. As mentioned above, glaucophane only originated in a deformational-metamorphic event in Shuangjiang area.

Suyi blueschist belt contains integral high P/T metamorphic mineral assemblage, glaucophane, aegirine-augite, phengite and lawsonite in Shuangjiang tectonic mélangé zone (Fig. 2).

**Nanlang blueschist belt**

Nanlang blueschist belt, located on the east of Suyi blueschist belt, is distributed in Nanlang ductile shear zone, being basically similar to Suyi ductile shear zone. But structural differentiation is more violent, and a lot of garnets occur along D₁S₁ structural schistosity, and it implies deeper structural level. High P/T metamorphic mineral, as Suyi blueschist belt as, is borne in muscovite-quartz glaucophane-schist and chlorite glaucophane-schist. But muscovite-quartz glaucophane-schist is more than
Suyi blueschist belt.

High P/T metamorphic mineral assemblage, distributing in D₃S₁ foliation, includes glaucophane, crossite and phengite and stilpnomalane, but no lawsonite. In general, D₂ generation metamorphic minerals are actinolite, albite and chlorite.

![Image](image_url)

**Figure 5.** (a). D₃S₁ continuous cleavage comprising glaucophane, albite and epidote and quartz lens. Suyi Section in Lancang County; (b). Columnar augite (Aug) porphyritic crystal, aegirine-augite (Aea) distributes in augite's crack, glaucophane (GL) in aegirine-augite's crack and actinolite (Act) in glaucophane's crack in order. Suyi Section in Lancang County; (c). Idiomorphic augite porphyritic crystal is wrapped by aegirine-augite and glaucophane and actinolite rim in order. Representing high P/T metamorphism is followed decreased pressure and increased temperature course. Suyi Section in Lancang County; (d). Glaucophane in D₃S₁ continuous cleavage is dragged to D₂S₂ crenulation cleavage, no new born glaucophane in D₂S₂ foliation. Suyi Section in Lancang County.

**Damanguangfang blueschist belt**

Damanguangfang blueschist belt, located on the west of Suyi blueschist belt, is distributed in Niujingshan ophiolite structural mélangé zone. High P/T metamorphic mineral is basically concentrated in Anya brittle-ductile shear zone, as main fault separated Shuangjiang structural mélangé zone and Gengma Late Paleozoic passive continental margin. The brittle-ductile shear zone, dipping east and dip angle 40°–60°, comprises Neoproterozoic Lancang Group and Carboniferous Niujingshan ophiolite mélangé and Permian Laba Formation, and is characterized by the westward thrusting. Two-stage regional foliations, D₃S₁ continuous flow cleavage and D₂S₂ discontinuous crenulation cleavage, are determined in the brittle-ductile shear zone. D₃S₁ foliation is parallel to the boundary of lithology, its forming mechanism is maybe related to layered shear. D₂S₂ foliation, no neonatal mineral occurrence and discontinuous mechanical crack, folded D₃S₁ foliation.

D₁ generation layered ductile shear zone embodies D₃S₁ flow cleavage zone and is characterized by ductile deformation, D₂ generation thrusting shear zone embodies dense crenulation cleavage zone, no penetration micro-crack displacement shows continuous flow in macro-scale and is characterized by brittle-ductile deformation.

Protolith glaucophane-bearing is basic volcanics, meta-basalt and tuff in Damanguangfang blueschist belt. In general, glaucophane is less than 5 %, exhibiting two occurrences, Columnar and fine glaucophane occurs in D₃S₁ flow cleavage. On the other hand, coronal glaucophane rim wrapping augite and altered rim are distributed along augite's crack.

However, it is worth the whistle that augite is also wrapped by aegirine-augite and glaucophane rim.
in succession in weak strain region (Fig. 6). The characteristics are thus comparable to the Suiy blueschist belt. But structural level, forming glauco-
phane, is obviously shallower than Suiy blueschist belt, according to the difference of deformation-
metamorphism in two blueschist belts.

\[ \text{inner jadeitic pyroxene (aegirine-augite)} \]
\[ \text{outer glauco-} \]
\[ \text{phane} \]
\[ \text{augite (main body)} \]
\[ \text{distal actinolite} \]

\[ \text{Figure 6. Ring texture around augite.} \]

**DISCUSSION AND CONCLUSION**

**Discussion**

There are different opinions to the origin of aegirine-augite and jadeitic pyroxene in Shuangjiang area. Some researches indicated that these minerals are magmatic ones and protolith glauco- 
phane-bearing rock belongs to ocean island alkaline basalt in tectonic environment (Zhong, 1998). The other, aegirine- 
augite is considered as a metamorphic mineral, jadeite- 
pyroxene. In this study, the features of aegirine-
augite and jadeitic pyroxene in Suiy and Damang-
guangfeng blueschist are as follows; ① all aegirine-
augites chiefly occur as reaction rim wrapping augite, 
no other occurrence; ② by probe mensuration, the 
mineral contains Al₂O₃=2.09 %–3.62 %, Na₂O= 
5.1 %–11.6 %, calculated terminal member mineral; 
Ac+Jd=39.6 %–67.1 %, and Jd=16.3 %– 
21.7 %, Di=16.0 %–27.3 %, and is low magnesi-
um, rich aluminium and natrium jadeite pyroxene, 
diopside-jadeite-aegirine series.

According to mineral occurrence and chemical 
components, aegirine-augite in Suiy blueschist and 
Damangguangfeng blueschist ought to be a metamor-
phic mineral instead of a magmatic mineral.

Date of isotopic chronology about blueschist in 
Shuangjiang area has important geological signi-
cance to study tectonic evolution of Paleozoic Tethys 
Sea. In this study, we obtain a grain zircon U-Pb 
ages (melting method), upper intercept ages of 
(282±19) Ma and lower intercept ages of (115±39) 
Ma from chloride glauco- 
phane-schist in Ankang Sec-
tion. The result is similar to Ar-Ar ages of 279 Ma, 
214 Ma and 111 Ma that Zhong (1998) obtained from 
west blueschist belt, Rb-Sr isochron ages of 240 Ma 
and 260 Ma from phengite (Zhou and Lin, 1982), 
⁴⁰Ar/³⁹Ar ages of 238 Ma also can be obtained 
(Zhong, 1998).

By regional tectonic evolution, Permian Laba 
Formation is drifted to D₃ generation deformation. 
Two group isotopic ages are dated from D₂ generation 
collision-type granite (like-porphyricit medium-coarse 
biotite monzonitic granite); one is 109–189. 4 Ma 
(K-Ar), and the other is 203–254. 5 Ma (zircon, U-
Pb). Foreland basin was formed in Late Triassic and 
filled by molasses formation, D₃ generation post-
collision volcanics intercalate Early Jurassic sedi-
mients, D₃ generation intracontinental orogenesis 
started in Middle Eocene. According to what men-
tioned above, the ages of 282 Ma and 279 Ma ought 
to represent glauco- 
phane forming, and 214–240 Ma 
reconstruction. As regards ⁴⁰Ar/³⁹Ar age of 
(409, 8±33, 6) Ma from glauco- 
phane and chlorite in 
Suiy blueschist, it perhaps implies the age of pro-
olith forming, because like-alkaline pillow basalt is 
found in Devonian Manxin Formation, distributed in 
Gengma passive continental margin.

Chlorite glauco- 
phane-schist in Shuangjiang is evi-
dently different from glauco- 
phane-bearing meta-basic igneous rock from Neoproterozoic Lancang Group in 
Huimin area. The former displays the feature of 
WPB (within plate basalt), but the latter displays 
the feature of island arc or active continental margin, 
enriched LREE and derived from enriched mantle 
(Zhong, 1998).

**Conclusions**

By means of study to glauco- 
phane-schist in 
Shuangjiang tectonic mélangé zone, we can get some 
important conclusions as follows.

(1) Two-stage ductile shear zones exist in 
Shuangjiang tectonic mélangé zone, glauco-
phane-schist distributes in D₁ generational layered ductile 
shear zone, high P/T mineral assemblage only origi-
nated in D₃S₃ foliation, Glauco- 
phane in D₂S₂ crenula-
cation cleavage, namely previous glauco- 
phane, has been dragged in D₂S₃ foliation. By the other words, 
in Shuangjiang area, there is only one-stage glauco-
phane, it occurs in layered ductile shear zone, it is 
the result of Changning-Menglian oceanic basin’s 
eastward subduction.

(2) There are three blueschist belts, Damang-
guangfeng belt, Suiy belt and Nanlang belt eastward 
in succession in Shuangjiang area, Metamorphic
grade is enhanced in order. High P/T mineral assemblage, reflecting different tectonic physical environments, is gradually changed. Damanguangfang belt is located at upper structural level, and protolith texture is basically remained, and main metamorphic minerals are chlorite, sericite and a few muscovites, and mineral assemblage of glaucophane±andesite pyroxene is a typical high P/T mineral assemblage. Main metamorphic minerals include glaucophane, chlorite, sericite-muscovite in Suyi blueschist belt, and glaucophane + jadeite pyroxene + lawsonite + phengite is a typical high P/T mineral assemblage. D$_3$S$_3$ foliation represents obvious ductile deformational feature. Glaucophane is originated in 350°C± by garnet-glaucophane geothermometer. The temperature is lower than 450°C, the pressure is 0.7 GPa, by amphibole-plagioclase geothermometer. These indicate shallow structural level, namely Suyi blueschist belt physical tectonic environment, Nanlang blueschist belt contains especially felsenrubin by contrast with Suyi blueschist belt. High P/T mineral assemblage includes crossite and phengite, a few glau-

cophane and jadeite pyroxene, no lawsonite. It is similar to high grade blueschist facies in west Alps. Crossite implies later stage of high P/T metamorphic environment, and temperature is higher, equivalent to epidote amphibolite facies and middle-shallow structural level.

3) Chlorite glaucophane-schist lens and matrix in Suyi and Nanlang area perhaps are derived from different protoliths respectively. Characteristics of the protolith are obviously different from meta-basalt in Neoproterozoic Lancang Group from Huimin area.

4) The ring texture, augite core is embraced by jadeitic pyroxene, glaucophane and actinolite in order, which basically reflects that high P/T metamorphism is overlapped by decreased pressure and increased temperature course. It also represents tectonic course of subduction→collision→exhumation.

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