# The $^{40}Ar/^{39}Ar$ geochronology constraint and geological significance of mylonites in Shangyi-Chicheng fault belt on the north of North China Craton

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**Abstract** A dating of two biotite samples taken from the meso- and low-temperature mylonites within the Shangyi-Chicheng fault belt on the north of the North China Craton yields $^{40}Ar/^{39}Ar$ isotopic ages of (399 ± 1) Ma and (263 ± 2) Ma, respectively. These data reflect an Early Devonian deformation and a Late Carboniferous retrograde metamorphism event along the fault, suggesting that the tectonic activities of the North China Craton in Paleozoic should be reconsidered.

**Keywords: Shangyi-Chicheng fault belt, mylonite, $^{40}Ar/^{39}Ar$ isotopic ages, re-activity fault.**

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The Shangyi-Chicheng fault belt extending along the south boundary of the Inner Mongolia axis on the north of the North China Craton was formed in the Middle Proterozoic. This fault has special geological significance1) in the evolution of the North China Craton for its revived events in the long course of the crust movements since its formation. The discussion on times of the tectonic activities of the fault, however, is limited in general to qualitative inference because the age determinations are rarely reported[1], and very few late-Proterozoic to Paleozoic deposits are found along this fault. These scarcities have increased the indetermination of the inferred ages of the tectonic activities.

This paper describes mylonites and deformations within the Shangyi-Chicheng fault belt, and presents two $^{40}Ar/^{39}Ar$ biotite dating results of mylonites. These data allow us to improve our understanding of the times for the fault activities in the middle and shallow crustal levels.

## 1 Geological setting and features of samples

The Shangyi-Chicheng fault belt, extending roughly along 41°N, is a major deeply dissected basement fault. It controlled the emplacement of a typical non-orogenic intrusion series (Rapakivi

1) Hu Ling , On the fault zone on the northern margin of Yanshan orogenic belt and its west section, Doctorate Dissertation of China University of Geosciences (in Chinese), 1999.

suite) in the Middle Proterozoic[2]; acted twice as a paleogeographic boundary blocking the invasion of platform seawater to the north in the Paleozoic, and controlled the occurrence of a series of coal basins and magmatism in the Early and Middle Jurassic, and revived again in the Cenozoic to provide a tunnel for the eruption of the Hannuoba basalt. It is still an important seismically active zone by now[3].

The mylonites in the Shangyi area of Hebei Province are distributed in the broken pieces of the metamorphic plutonic rocks contained in the Shangyi-Chicheng fault belt. Due to the multiple reforming of brittle deformation, some of the mylonite pieces have been thrusted onto the Lower Jurassic Xiahuayuan Formation, and the Upper Jurassic Houcheng Formation overlapped unconformably these mylonitic rocks (fig. 1). The metamorphic rocks had undergone a metamorphism of amphibolite facies under the conditions of temperature range of 592—650℃ and pressure of 0.47 GPa. The mylonitization of the metamorphic rocks resulted from the post-retrograde metamorphism and deformation from epidote-amphibolite facies to high green-schist facies (under the conditions of temperature range of 450—500℃ and pressure range of 0.2—0.3 GPa), and then they underwent another post-retrograde metamorphism of low green-schist facies (under the conditions of temperature of 350℃ and pressure range of 0.1—0.2 GPa). These phenomena indicate that the old metamorphic rocks experienced complicated deformation and metamorphism in the

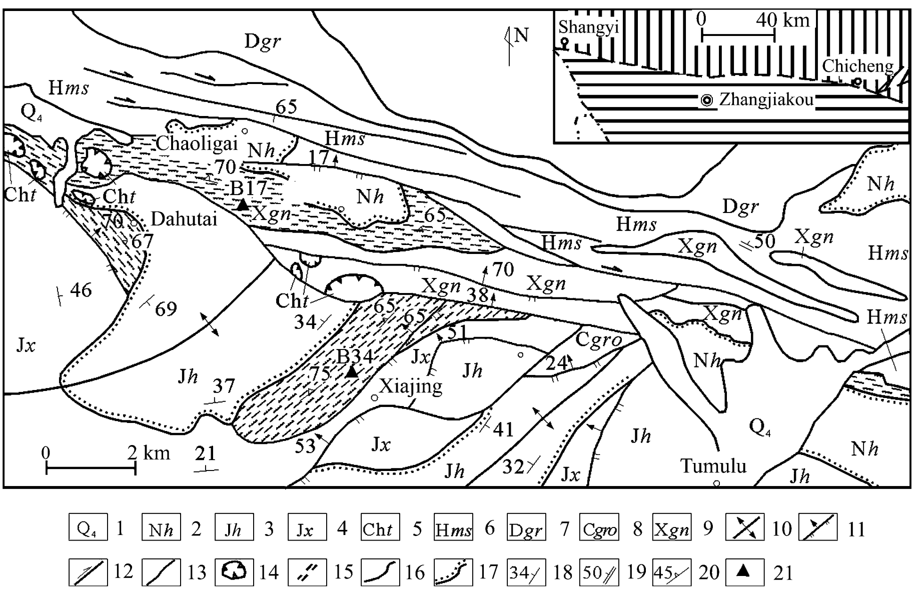


Fig. 1. A tectonic sketch of Huangtuyao, Shangyi area, Hebei Province[4]. 1, Quaternary; 2, Hannuoba Formation; 3, Jurassic Houcheng Formation; 4, Jurassic Xiahuayuan Formation; 5, Tuanshanzi Formation of Changcheng series; 6, Paleo-Proterozoic Dabagou gneissic granite; 7, Paleo-Proterozoic Changhanying gneissic plagiogranite; 8, Neo-Archean Huangtuyao Formation; 9, Neo-Archean Xiajing gneiss (diorite); 10, syncline axis; 11, thrust fault; 12, strike-slip fault; 13, fault; 14, klippe; 15, ductile shear zone; 16, geological boundary; 17, unconformity; 18, attitude of stratum; 19, attitude of schist; 20, attitude of mylonitic foliation; 21, sample locations for age determination.

course of their elevation and evolution[1)].

Sample B34 was taken from the broken pieces of the mylonite overlapping the Xiahuayuan Formation. It is mainly composed of plagioclase (40%), quartz (30%), biotite (15%), epidotite (5%), muscovite (2%), chlorite (3%), magmetite (2%) and titanite (1%), of which the muscovite and chlorite were formed in the later stage of retrograde metamorphism. The rock has characteristics of blastomylonitic structure (fig. 2) with such peculiar features as plagioclase porphyroid and core and mantle structures. The microprobe analysis of the plagioclase shows a slight decrease in the An numbers of 26.3, 27.1 and 21.4 from the core, the margin of porphyroid to the new grain, respectively. The quartz shows a band structure of polycrystalline aggregate in somewhat rectangular form with the grain size ranging from 0.15 mm to 0.2 mm. The biotite shows dark green pleochroism in small flake form and coexists with the fine grain minerals of plagioclase, quartz and epidotite, and the epidotite takes the granular, acicular or prismatic form. The recrystallized mineral assemblage is composed of plagioclase + quartz + biotite + epidotite, reflecting the metamorphism of epidotite-amphibolite facies.

Sample B17 was taken from the approximately EW-strike mylonite belt. It is mainly composed of plagioclase (45%), quartz (30%), biotite (5%), muscovite (8%), chlorite (8%) and magnetite (3%). The rock is characterized by typical porphyclastic mylonitic structures (fig. 2) with such deformed features as plagioclase porphyroid and core and mantle structures. The ratio of length/width for the porphyroid is from 1 to 2. The quartz shows polygonized and recrystallization microstructures, and has the grain size ranging from 0.08 mm to 0.1 mm. The biotite is mainly concentrated into dark mineral bands，showing brownish yellow pleochroism with scattering relics of brownish red pleochroism grains. The recrystallized mineral assemblage is composed of plagioclase + quartz + biotite, equivalet to the metamorphism of high green-schist facies. The deformed rocks, however, have been reformed by an obvious retrograde metamorphism，as evidenced by the facts that the biotite is strongly chloritized with a little muscovite on the margins, and the porphyroid of plagioclase is sericitized, with the albitization margins and new grains (microprobe analysis shows that the An numbers are recorded as 24, 15 and 6 from the core to margin of porphyroid and new grain, respectively). The muscovite flakes are mainly found in the tail parts of the plagioclase. The retrograde metamorphic mineral assemblage is composed of albite + lepidomorphite + chlorite, which reflects the metamorphism of lower green-schist facies.

The temperature and pressure conditions for the deformation and metamorphism of meso-thermal mylonite of B34 is a bit higher than those for B17, which indicates that B34 lay at a relatively great depth in the crust during the deformation, and the retrograde metamorphism was much weaker.

## 2 Analysis results

Two mylonite samples taken from the fault were sellected, and biotites were separated for

1) See the footnote on page 1134.

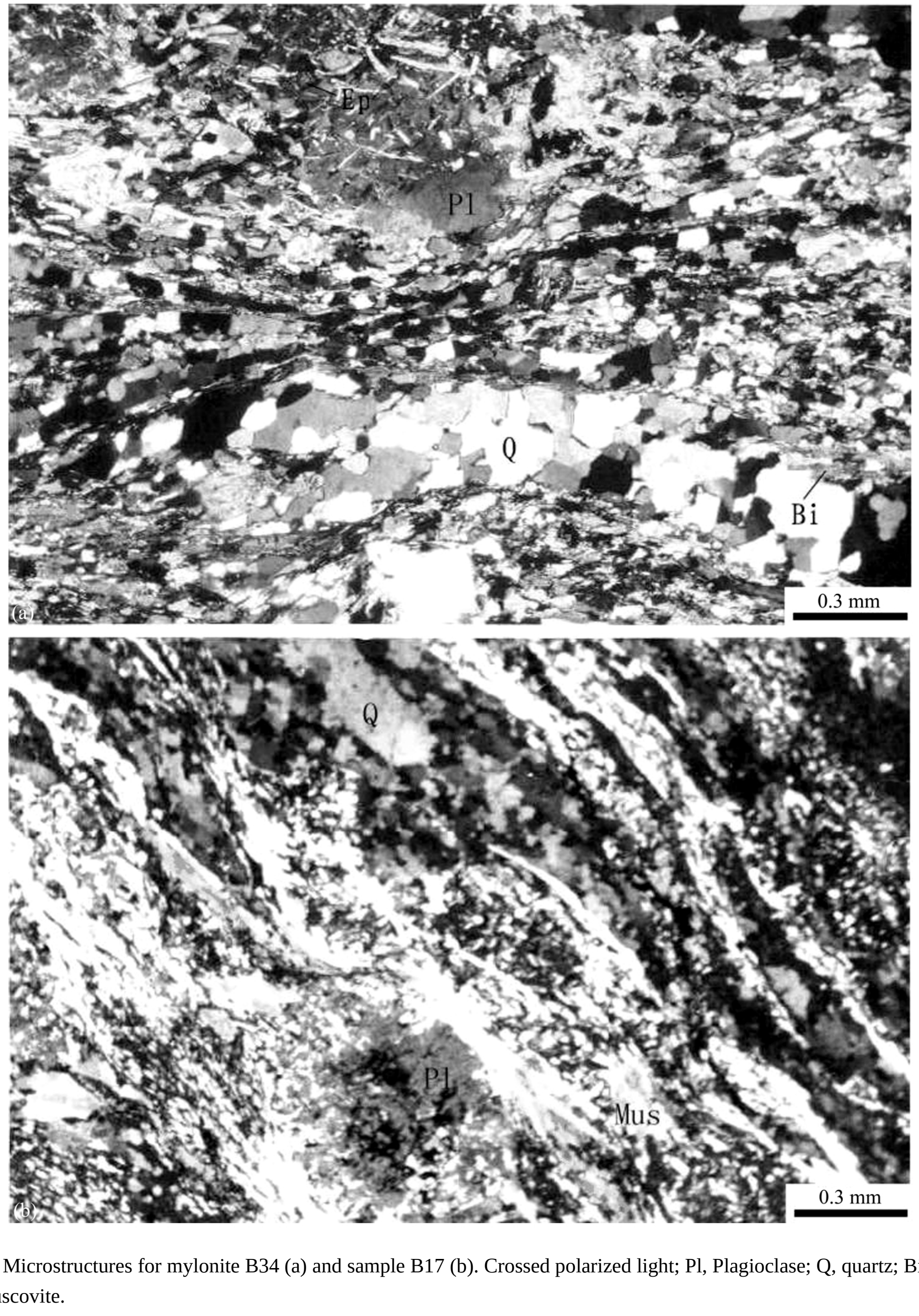


Fig. 2. Microstructures for mylonite B34 (a) and sample B17 (b). Crossed polarized light; Pl, Plagioclase; Q, quartz; Bi, biotite; Mus, muscovite.

$^{40}Ar/^{39}Ar$ geochronology dating (fig. 1). The biotites were irradiated in the 49-2 reactor at the Institute of Atomic Energy, the Chinese Academy of Sciences. The $^{40}Ar/^{39}Ar$ step-heating analyses were conducted at the Institute of Geology, the Chinese Academy of Geological Sciences. The system employs mm1200 for samples heated from 390℃ to 1400℃ with interval ranging from

90℃ to 120℃. The analysis results are shown in table 1 and the $^{40}Ar/^{39}Ar$ age spectrum in fig. 3.

Table 1 Results of $^{40}Ar/^{39}Ar$ age dating of the biotites

| $T$/℃ | $(40/39)_m$ | $(36/39)_m$ | $(37/39)_m$ | $*^{40}Ar/^{39}Ar$ a) | $^{39}Ar$ ($\times 10^{-14}$ mol) | Age/Ma | $^{39}Ar$ (%) |
|---|---|---|---|---|---|---|---|
| Sample B34 (biotite), 98.9 mg, irradiation parameter $J$ = 0.012948 | | | | | | | |
| 400 | 12.4776 | 0.0096 | 0.1399 | 9.6611 | 335.00 | 212.60 ± 2.40 | 4.63 |
| 500 | 17.9083 | 0.0047 | 0.0671 | 16.5121 | 698.00 | 349.50 ± 3.40 | 14.29 |
| 600 | 19.4728 | 0.0018 | 0.0359 | 18.9309 | 1176.00 | 395.50 ± 3.70 | 30.56 |
| 700 | 19.9024 | 0.0024 | 0.0076 | 19.2016 | 615.00 | 400.60 ± 3.80 | 39.06 |
| 800 | 19.9628 | 0.0034 | 0.1047 | 18.9765 | 269.00 | 396.30 ± 3.70 | 42.79 |
| 900 | 19.5980 | 0.0023 | 0.1099 | 18.9097 | 299.00 | 395.10 ± 3.70 | 46.92 |
| 1000 | 19.8608 | 0.0018 | 0.0730 | 19.3243 | 934.00 | 402.90 ± 3.80 | 59.84 |
| 1100 | 20.0000 | 0.0020 | 0.0458 | 19.4212 | 409.00 | 404.70 ± 3.80 | 65.50 |
| 1200 | 20.0151 | 0.0017 | 0.0354 | 19.5224 | 1324.00 | 406.60 ± 3.80 | 83.82 |
| 1300 | 19.9052 | 0.0014 | 0.0370 | 19.4835 | 633.00 | 405.80 ± 3.80 | 92.57 |
| 1400 | 19.8138 | 0.0017 | 0.0524 | 19.3183 | 537.00 | 402.70 ± 3.80 | 100.00 |
| Sample B17 (biotite), 109.4 mg, irradiation parameter $J$ = 0.012405 | | | | | | | |
| 390 | 18.2499 | 0.0361 | 0.2295 | 7.5806 | 90.57 | 162.10 ± 8.50 | 3.11 |
| 480 | 16.4144 | 0.0314 | 0.4614 | 7.1761 | 97.12 | 153.80 ± 4.10 | 6.44 |
| 580 | 14.3080 | 0.0195 | 0.0410 | 8.5421 | 263.69 | 181.70 ± 3.00 | 15.49 |
| 680 | 15.6648 | 0.0098 | 0.6432 | 12.8016 | 410.60 | 265.90 ± 3.00 | 29.58 |
| 780 | 14.0199 | 0.0047 | 0.2966 | 12.6641 | 502.81 | 263.20 ± 2.70 | 46.83 |
| 880 | 14.3280 | 0.0057 | 0.0903 | 12.6605 | 437.54 | 263.20 ± 2.90 | 61.85 |
| 980 | 14.3034 | 0.0057 | 0.0377 | 12.6309 | 350.74 | 262.60 ± 3.00 | 73.88 |
| 1080 | 14.3285 | 0.0052 | 0.0689 | 12.7944 | 431.51 | 265.70 ± 2.80 | 88.69 |
| 1190 | 21.0698 | 0.0098 | 0.1611 | 18.1866 | 272.81 | 367.00 ± 4.00 | 98.05 |
| 1280 | 40.8416 | 0.0696 | 0.2714 | 20.2958 | 22.82 | 405.10 ± 6.90 | 98.84 |
| 1400 | 42.2634 | 0.0629 | 1.2528 | 23.7769 | 33.93 | 466.30 ± 15.60 | 100.00 |

a) ∗ indicates the radiogenic argen.

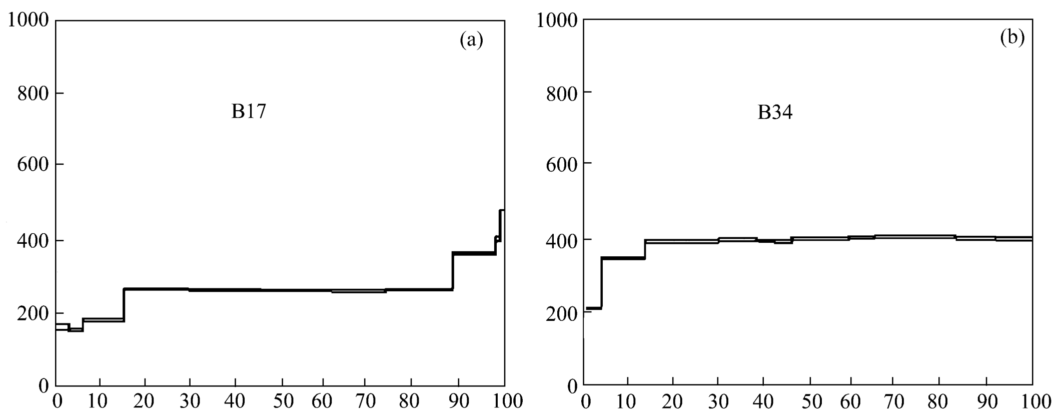


Fig. 3. $^{40}Ar/^{39}Ar$ ages of the biotites separated from the mylonite of Shangyi-Chicheng fault belt.

The isotopic plateau age of biotite from sample B34 is (399 ± 1) Ma for 85% of the $^{39}Ar$ emitted, and 14.92% of the $^{39}Ar$ emitted in the temperature heating range of 400℃—500℃. The isochronal age is 423.1 Ma with the initial $^{40}Ar/^{36}Ar$ ratio of 323.3. The flat plateau age from 600

℃ to 1400℃ suggests that the argon should not have obviously disrupted at the later low temperature stage of forming closed system of the biotite (the lowest closed temperature of biotite is about 300℃±[5]). The isochronal age (423.1 Ma) is older than that of plateau age (399 Ma), meaning a minor loss of the $^{39}$Ar in the biotite of B34.

The isotopic plateau age of biotite from sample B17 is (263 ± 2) Ma for 73% of the $^{39}$Ar emitted, and 15.5% of argon emitted in the lower temperature heating stage and 10% in higher temperature heating stage. This may indicate that the biotite of B17 had $^{39}$Ar loss at later stage and had relic argon before the biotite's system closed. The isochronal age is 261.6 Ma corresponding to heating stages 4—8 with the initial $^{40}$Ar/$^{36}$Ar ratio of 312.8. Its plateau age (263 Ma) is similar to the isochronal age (261.6 Ma), meaning no excess argon in the plateau age in biotite of B17.

According to the petrologic and microstructural features of the samples, the main plateau age ((399 ± 1) Ma) of biotite of B34 represents the time of the ductile deformation and mylonitization during the later stage of the Caledonian orogeny in Early Devonian. The plateau age was only slightly affected by the later low temperature retrograde metamorphism. Moreover, we have also obtained a K-Ar age of (349.2 ± 5.66) Ma for the biotite of sample B34. This age is similar to the low plateau age ((349.5 ± 3.40) Ma) and smaller than the main plateau age ((399 ± 1) Ma), and it seems that the biotite slightly suffered low temperature retrograde metamorphism with some kalium loss. Therefore, the (399 ± 1) Ma isotopic age of the biotite of sample B34 is reliable.

The biotites of sample B17 underwent strong chloritization in the later retrograde metamorphism of low green-schist facies, thus the main plateau age should represent the time of this metamorphism, and this age corresponds to Late Carboniferous. The relic argon shows that the biotite was incompletely modified during the later retrograde metamorphism. Moreover, the biotite might be affected again by a low-temperature metamorphism in another later period. Wang[1] collected one mylonite sample in the same shear zone in Chicheng County for the hornblende chronology of $^{40}$Ar/$^{39}$Ar, and obtained a main plateau age of hornblende of (211.35 ± 2.26) Ma, which is obviously younger than that of biotite of this study. This may show that this fault underwent deformation and metamorphism again in the later Indosinian event.

## 3 Discussion on the geological significance

It is believed that the North China Craton was in a steady elevation and subsidence of the earth crust from the Late Proterozoic and then re-activated in the Triassic[6,7]. But some new data show that this idea should be reconsidered. For instance, there have been reports[6,8] on Rb-Sr ages of mica and U-Pb ages of ilmenite (450—490 Ma) from the kimberlites in Mengyin of Shandong Province and Fuxian County of Liaoning Province, tectonically within the North China Craton. These ages imply an intracontinental extensional tectonics, but no relevant thermo-tectonic event has been recognized up to now. This should be a deeply doubtful point to the tectonics in Paleozoic for the craton.

In early Paleozoic, the northern oceanic plate subducted to the North China Craton. Therefore, there might be a suture zone on the northern margin of the craton[6]. A typical example is the ultramafic and mafic volcanic rocks exposed in the Wendurmiao area in the central Inner Mongolia. These rocks bear some well-developed characteristics of ophiolitic suite, have yielded an isotopic age of 632—509 Ma (K-Ar), and are unconformably overlaid by the Upper Silurian Xibiehe Formation. The ophiolitic suite suffered a metamorphism of glaucophane-schist facies at the ages of (435 ± 61) Ma and 386 Ma (Rb-Sr), respectively. In addition, two stages of later metamorphic reforms (340 Ma and 287 Ma ) are observed in the suite. The intrusive acid rocks yield K-Ar age of 408 Ma and Pb-Pb age of 400 Ma[6].

It is believed that the North China Craton was connected with the Siberia plate in the late Paleozoic. So there are a series of intrusive and volcanic rocks around north margin of the North China Craton. The plutons within the North China Craton (on the north of the Shangyi-Chicheng fault belt) are composed of granites with an age of 262—284 Ma[9]. The acid plutons to the north of the craton usually intruded into the Lower Permian and overlaid by the Upper Permian, and have the age of 250—260 Ma[6].

The above tectonic events seem to correspond to the formation of mylonite and metamorphism within the Shangyi-Chicheng fault, and as mentioned above, these events are dated to 399 Ma and 263 Ma, respectively. Therefore, the Shangyi-Chicheng fault appears to be a paleo-fault as a weaker zone within the North China Craton, and was re-activated in the later Caledonian movement. It is suggested that this thermo-tectonic event was induced by the subduction event in the Caledonian stage on the north side of the craton. In the Late Permian, the fault belt experienced a lower-temperature retrograde metamorphism once more. Moreover, the fault belt might underwent another deformation or metamorphism in the later Indosinian movement.

The features of deformation and metamorphism in the Shangyi-Chicheng fault may suggest that the reactivation of the long-living faults within the craton have an important significance in the intraplate deformation. This opinion has also been proposed at the "Continental-Interior Tectonics" conference held in the USA in 1997, emphasizing the control of fault reactivation over the tectonics within cratons[10—12]. The isotopic ages of the mylonites within the Shangyi-Chicheng fault show a multiphase and long-term deformation and metamorphism history. It is suggested that it be also necessary to reconsider the tectonic evolution of the North China Craton in the Paleozoic.

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