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## FORMATION OF RUBY IN THE RED RIVER METAMORPHIC ZONE

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**Summary.** Numerous gem-quality rubies have been found in Luc Yen marbles and Day Nui Con Voi metamorphic zone. The Red River shear zone is composed a narrow high grade gneiss range of strongly foliated and lineated, mylonitic gneisses. Numerous shear criteria, indicate that the gneisses have undergone intense, progressive left-lateral shear. High temperature shear was coeval with the emplacement of leucocratic melts. Left-lateral deformation, coeval with crystal partial fusion and leucocratic melts emplacement, took place at moderate pressure (4-8 kb) and high temperatures (650-850°C). Biotite ages are comprise between 23 and 25 Ma, 33-40 Ma age of a muscovite suggest that such high temperature left-lateral deformation lasted since circa 40 Ma. The Day Nui Con Voi corundum that are found in, and at the contact of leucocratic melts, thus probably crystallized between 40 and 33 Ma during left-lateral shear. Phlogopite extracted from sample V161 yield a  $^{40}\text{Ar}/^{39}\text{Ar}$  plateau age of  $32 \pm 1.8$  Ma. We interpret this age as that of the coeval crystallization of ruby and phlogopite. Corundum crystallized on, or at the contact of, intrusive melts between 40 and 33 Ma in the Day Nui Con Voi shear zone, and around  $32 \pm 1.8$  Ma in Luc Yen.

In past years, numerous gem-quality rubies have been found in Camprian marbles near the city of Luc Yen north of the Day Nui Con Voi metamorphic zone in North Vietnam. Lately the gemstones have also been found in pegmatites within this metamorphic zone (Tan Huong mine and numerous other small mines). Here we provide evidence that these rubies formed in the Tertiary during a major tectono-metamorphic event associated with large-scale left-lateral movements along the Ailao Shan-Red River shear zone.

The Alao Shan-Red River shear zone (ASRR) is the major geological discontinuity in East Asia. It stretches for more than 1000 km from SE Tibet to the South China Sea and is composed of four narrow (< 20 km wide) high grade gneiss ranges: the Day Nui Con Voi in North Vietnam, and the Ailao, Diancang and Xuelong Shan in Yunnan. Until recently, these high grade rocks were considered to be of Proterozoic age. A detailed study of the



four ASRR metamorphic ranges shows that the gneiss cores of these ranges are composed of strongly foliated and lineated, mylonitic gneisses (e.g., [4]). The foliation is usually

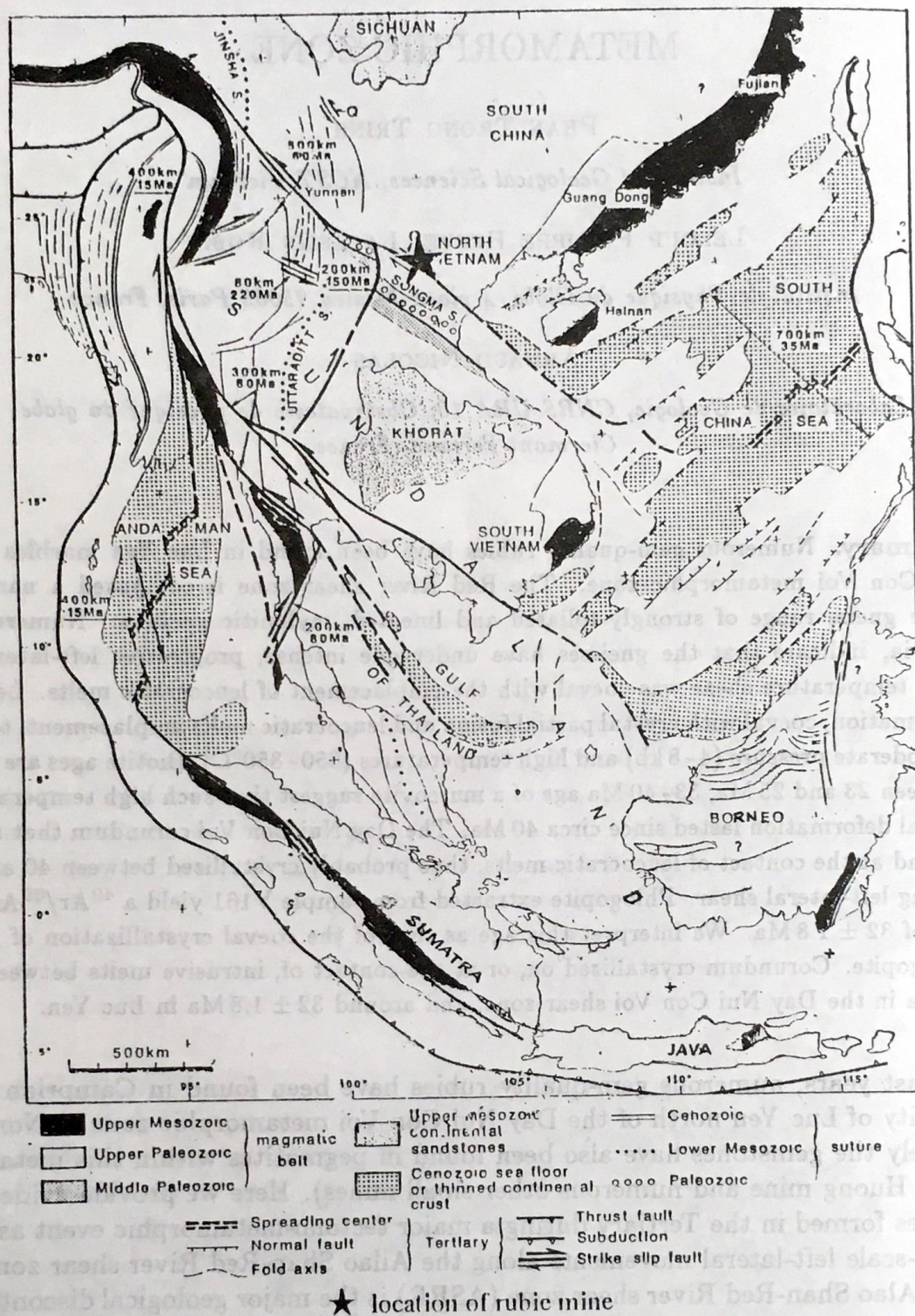


Fig. 1. Position of ruby mines in the schematic structural map of Red river metamorphic zone in Southeast Asia. (from model of Pelzer and Tapponnier, 1988)



steep and bears a horizontal stretching lineation, both being almost parallel to the local trend of the gneissic cores. In some places, foliation dips more gently, nevertheless lineations always stay horizontal and parallel to the trend of the belt. Numerous shear criteria indicate that the gneisses have undergone intense, progressive left-lateral shear. Petrologic studies show that left-lateral strain occurred under amphibolite facies conditions in the Ailao Shan range (3-7 kb and 550-780°C), ([3, Fig. 3]). In all ranges high temperature shear was coeval with the emplacement of leucocratic melts. Such deformed melts yield U/Pb ages between 22.4 and 26.3 Ma in the Ailao Shan and Diancang Shan, implying shear in the Lower Miocene (e.g., [7]).

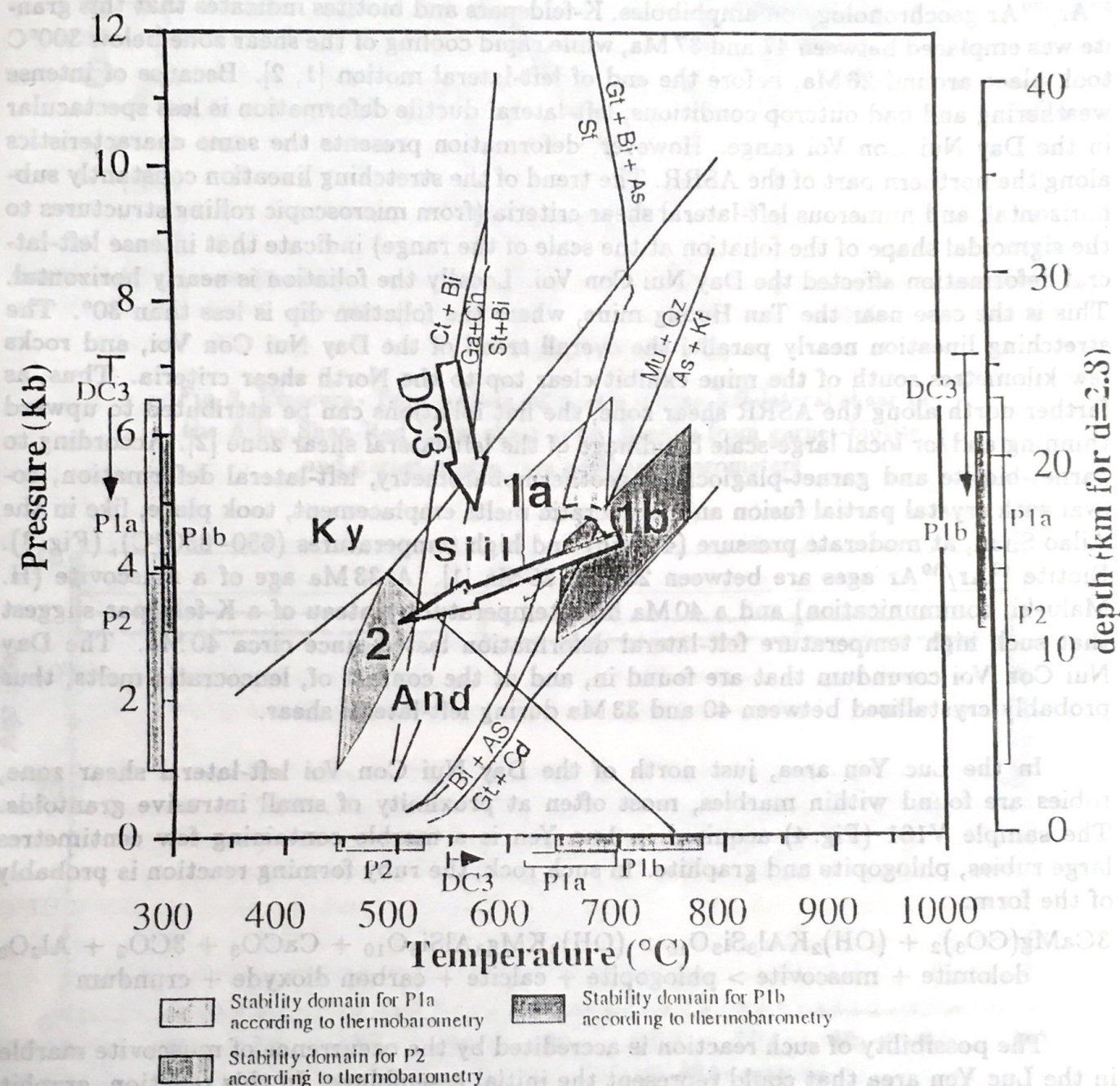


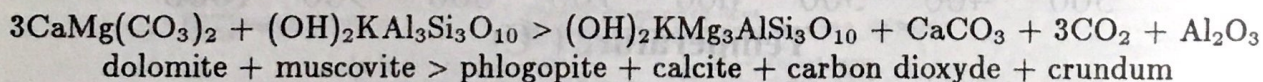
Fig. 2. Pressure-Temperature evolution of Ailao Shan and Diancang Shan gneisses, the segments of the Red River metamorphic zone (from Leloup and Kienas, 1993)



Mylonites in these two ranges rapidly cooled to 300°C between 22 and 17 Ma, before the end of left-lateral motion [1]. The total left-lateral offset is estimated at 700-1200 km [2], while the rate was on the order of 3 to 5 cm/yr [1].

In Vietnam, the southern extension of the Ailao shan range outcrops in the Bat Xat - Lao Cai Area, while the Day Nui Con Voi range can be followed from Lao Cai to Viet Tri and even Ninh Binh where high-grade metamorphic rocks pinch out from below the Quaternary fill of the Hanoi Basin. A cross section at the level of Bat Xat reveals beautiful evidences for left-lateral strike-slip ductile deformation. Farther South the Fan Si Pan granite which is probably syntectonic, is affected by a large scale left-lateral shear plane.  $^{40}\text{Ar}/^{39}\text{Ar}$  geochronology on amphiboles, K-feldspars and biotites indicates that this granite was emplaced between 47 and 37 Ma, while rapid cooling of the shear zone below 300°C took place around 26 Ma, before the end of left-lateral motion [1, 2]. Because of intense weathering and bad outcrop conditions, left-lateral ductile deformation is less spectacular in the Day Nui Con Voi range. However, deformation presents the same characteristics along the northern part of the ASRR. The trend of the stretching lineation constantly sub-horizontal, and numerous left-lateral shear criteria (from microscopic rolling structures to the sigmoidal shape of the foliation at the scale of the range) indicate that intense left-lateral deformation affected the Day Nui Con Voi. Locally the foliation is nearly horizontal. This is the case near the Tan Huong mine, where the foliation dip is less than 30°. The stretching lineation nearly parallel the overall trend of the Day Nui Con Voi, and rocks few kilometres south of the mine exhibit clear top to the North shear criteria. Thus, as farther north along the ASRR shear zone, the flat foliations can be attributed to upward thinning and/or local large-scale boudinage of the left-lateral shear zone [2]. According to garnet-biotite and garnet-plagioclase, geothermobarometry, left-lateral deformation, coeval with crystal partial fusion and leucocratic melts emplacement, took place, like in the Ailao Shan, at moderate pressure (4-8 kb) and high temperatures (650-850°C), (Fig. 3). Biotite  $^{40}\text{Ar}/^{39}\text{Ar}$  ages are between 23 and 25 Ma [1]. A 33 Ma age of a muscovite (H. Maluski, communication) and a 40 Ma high temperature plateau of a K-feldspar suggest that such high temperature left-lateral deformation lasted since circa 40 Ma. The Day Nui Con Voi corundum that are found in, and at the contact of, leucocratic melts, thus probably crystallized between 40 and 33 Ma during left-lateral shear.

In the Luc Yen area, just north of the Day Nui Con Voi left-lateral shear zone, rubies are found within marbles, most often at proximity of small intrusive grantoids. The sample V161 (Fig. 4) acquired in Luc Yen is a marble containing few centimetres large rubies, phlogopite and graphite. In such rock, the ruby forming reaction is probably of the form:



The possibility of such reaction is accredited by the occurrence of muscovite marbles in the Luc Yen area that could represent the initial assemblage. In this reaction, graphite formation could result from carbon dioxide dissociation if oxygen is either degassed or combined with excess Mg and Al to form spinel ( $\text{MgAl}_2\text{O}_4$ ), a mineral commonly found within the Luc Yen marbles. Phlogopite extracted from sample V161 yield a  $^{40}\text{Ar}/^{39}\text{Ar}$



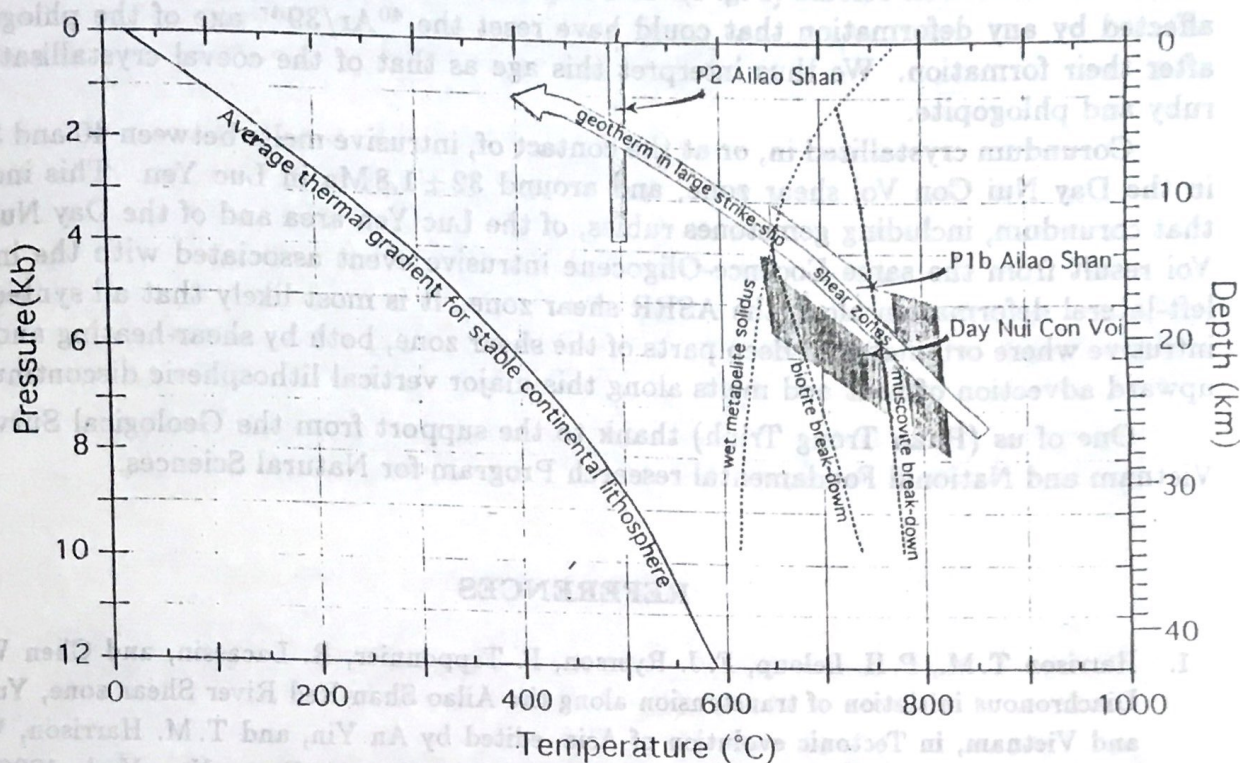


Fig. 3. Pressure - Temperature estimates during left-lateral shear in the Ailao Shan-Red River shear zone. Results from garnet-biotite and garnet-plagioclase geothermobarometers

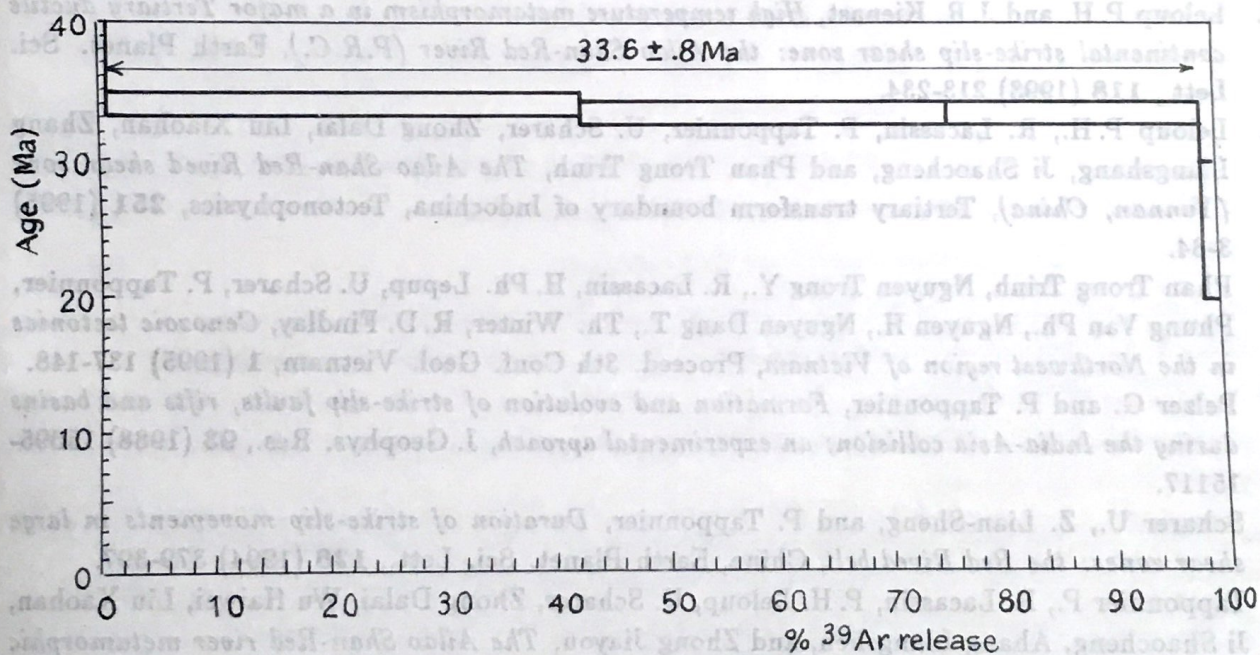


Fig. 4. V161 phlogopite  $^{39}\text{Ar}/^{40}\text{Ar}$  age spectrum. V161 contains ruby, phlogopite and graphite



plateau age of  $32 \pm 1.8$  Ma, calculated on 3 consecutive heating steps the correspond to 98% of the total  $^{39}\text{Ar}$  release (Fig. 4). It is important to note that 161 appears to not have affected by any deformation that could have reset the  $^{40}\text{Ar}/^{39}\text{Ar}$  age of the phlogopites after their formation. We thus interpret this age as that of the coeval crystallisation of ruby and phlogopite.

Corundum crystallized in, or at the contact of, intrusive melts between 40 and 33 Ma in the Day Nui Con Voi shear zone, and around  $32 \pm 1.8$  Ma in Luc Yen. This indicate that corundum, including gemstones rubies, of the Luc Yen area and of the Day Nui Con Voi result from the same Eocene-Oligocene intrusive event associated with the intense left-lateral deformation along the ASRR shear zone. It is most likely that all syntectonic intrusive where originated in deep parts of the shear zone, both by shear-heating and easy upward advection of heat and melts along this major vertical lithospheric discontinuity.

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