[PS]Fluid Inclusion and Isotope Studies of Calcite Veins in Shizhu Synclinorium, Central China: Record of Origin of Fluids and Diagenetic Conditions*

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Abstract

Calcite veins occur widely in carbonate strata in Shizhu synclinorium of the foreland fold belt settings of western Mid-Yangtze of central China, and proverbially, fluid activities cause the precipitation of calcites. This study is focused on the origin and timing of paleofluid activity events in Paleozoic and Mesozoic carbonate strata of Shizhu synclinorium using basin modeling technology and petrographical observation with the data from isotope and fluid-inclusion of these calcite veins. Two successive generations of fracture-filling calcite cements are distinguished based on microscopy and cathode luminescence. The older calcites (Stage 1) are moderate red luminescence, isometric texture and exhibit intense cleavage. The melting temperatures of two-phase aqueous inclusions in Stages 1 calcites have values between -8.9 and -18.9 C, corresponding to a range in salinity between 12.73 and 21.61 eq. wt% NaCl. Homogenization temperatures display a wide range (78.6-215.5 °C) in each sampling stratum. Fluid inclusion microthermometric analysis indicates that there existed four to five fluid activity episodes. The δ^{18}OV-PDB values of Stage 1 calcites (-12.94‰ to -6.77‰) are found to be more negative than those of host rocks (-10.81‰ to -4.38‰). The majority of the ^{87}Sr/^{86}Sr ratios of those calcites in each stratum vary in the range of coeval seawater. The significantly positive values of the calculated δ^{18}O values of fluids-precipitating calcites (-0.41‰ to 14.42‰, SMOW) and ^{87}Sr/^{86}Sr ratios varying in the range of coeval seawater suggest fluids-forming calcites in each stratigraphic unit could be due to the involvement of fluids that originated from coeval seawater and evolved through different degrees of water rock interaction. The younger Stage 2 calcites have only been encountered in the central parts of a few thick veins. These calcites are characterized by an intensely zoned luminescence pattern, with bright red, dull red and non-luminescent zones, which is interpreted to have precipitated from shallower meteoric waters. Fluid-inclusion data combined with basin modeling indicate various episodes of evolved basinal fluids flow through formation fractures spanning a time frame from 135 to 50Ma, the veins probably reflect episodes of fluid flow that initiated by tectonic compression and uplift during Late Yanshanian and Early Himalayan orogeny.

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Fluid Inclusion and Isotope Studies of Calcite Veins in Shizhu Synclinorium, Central China: Record of Origin of Fluids and Diagenetic Conditions

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1. Objectives and significances

- Present the origin and timing of paleofluid activity events in Paleozoic and Mesozoic carbonate strata of Shizhu synclinorium.
- provide an evaluation of oil and gas preservation conditions of the study area

2. Geological background

The Shizhu synclinorium lies in the western Hubei and eastern Sichuan regions of the western part of Mid-Yangtze, delimited by the Qiyueshan anticlinorium and the Fangdoushan anticlinorium covering an area of about 4300 km^2.The area represents the front edge of the thrust nappe of the Jiangnan-Xuefeng orogenic belt, and belongs to the western Hunan -Hubei and eastern Sichuan tectonic belt (Fig. 1A). The regional tectonic direction is NE, NNE. Since the Sinian the area has experienced the Paleozoic Caledonian-Hercynian, Triassic Indosinian and Jurassic-Cretaceous Yanshanian and Cenozoic Himalayan activities, which controlled the tectonic evolution of the study area.

Marine strata were deposited in the study area from the Early Sinian period of the Late Proterozoic to the Middle Triassic of the Mesozoic era. The Indosinian movement during the Late Triassic ended the marine deposition of sediments and initiated the continental deposition in the foreland until the Jurassic (Fig. 1C). The Late Yanshanian Orogeny in the Cretaceous caused the study area to experience strong folding, uplift and erosion, and exposing Palaeozoic and Mesozoic strata.

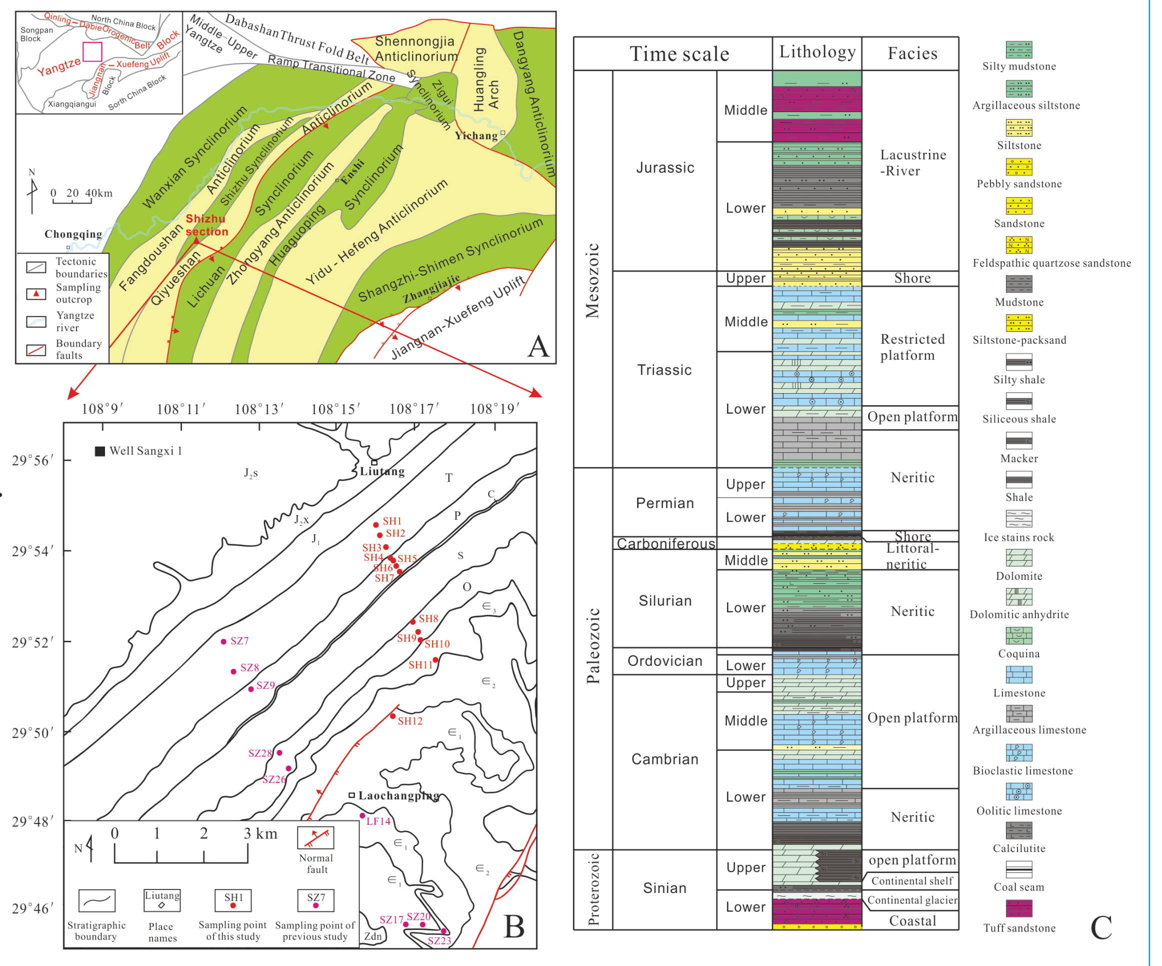


Fig.1. (A) Structural sketch map of the Shizhu synclinorium in the western region of Mid-Yangtze. (B) Simplified geological map showing the position of the sampling profile. (C) Schematic lithostratigraphic column of the Shizhu synclinorium in the western region of Mid-Yangtze.

3. Samples

For this study, fresh outcrop samples of calcite veins and adjacent host rocks were collected from Cambrian, Ordovician, Permian and Triassic carbonate strata in the Shizhu synclinorium. **The majority of the samples studied were collected from subvertical veins and locally high-angle (70-80°) veins with respect to bedding.** Their vertical persistence varies from few centimeters to several meters, whereas the vein width ranges from several millimeters to a maximum of 20 centimeters. The veins represent open fractures filled with calcite. Therefore, geochemical analyses of the veins provide a record of the nature and properties of the subsurface fluids that have migrated through the rock at various times. Sample locations are given in Fig 1B. Fluid-inclusion, stable (oxygen, carbon) isotope, and strontium isotope studies were carried out on the samples.

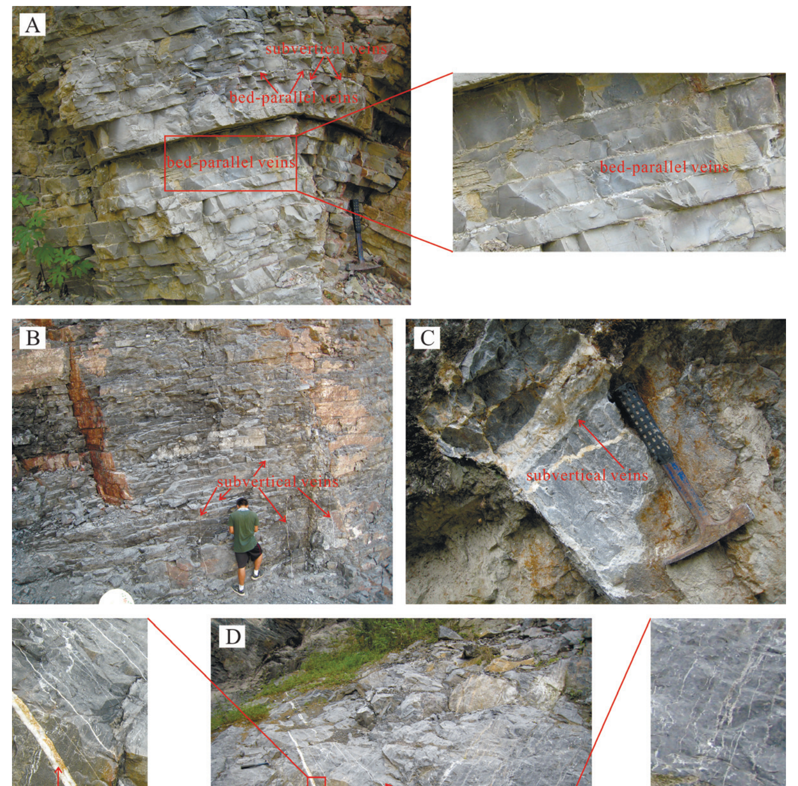


Fig. 2. Outcrop images of calcite veins hosted in marine carbonate rocks in the Shizhu synclinorium

4. Petrography of calcite veins

Calcite has diverse crystal shapes (equant/ blocky, or fibrous) and color (milky to white-yellow), and grows symmetrically from each wall into the interior of the fractures (Fig. 3A). **Many veins appear as composite veins containing crack-seal textures in which the first stage of calcite cement was fractured and pulled apart followed by the emplacement of a late stage calcite cement (Fig. 2D; Fig. 3B and C).** These observations indicate multiple phases of fracture opening and cement precipitation. Veining and subsequent crystallisation of vein minerals are complex multistage processes rather than a single event.

On the basis of microscopy and cathodoluminescence (CL) petrography, the calcite in the study area has been classified into **three groups**. In veins displaying crack-seal textures calcite vein, **the early stage calcite (Stage 1)** shows a moderate red luminescence (Fig. 3C, D). Two crystal morphologies were identified in Stage 1 calcite veins, which are filled with coarse-crystalline equant and radiating crystals, with cloudy transparency (Fig. 3B, C). **The later stage calcite (Stage 2)** represents a younger cement phase and shows a dull-red luminescence (Fig. 3C, D). Stage 2 calcite crystals have isometric textures and are more transparent (Fig. 3B, C). **The youngest (Stage 3)** calcite growing in the central parts of some thick calcite veins shows an intensely zoned luminescence pattern, with bright red, dull red and non-luminescent zones (Fig. 3E, F). Stage 3 calcite is generally non-deformed. It represents well-crystallised calcite aggregates that grew in open spaces. The intensely zoned pattern is often interpreted as meteoric cements, which are formed at shallow depth and low temperatures (Meyers, 1974, 1978; Grover and Read, 1983; Suchy et al., 2000).

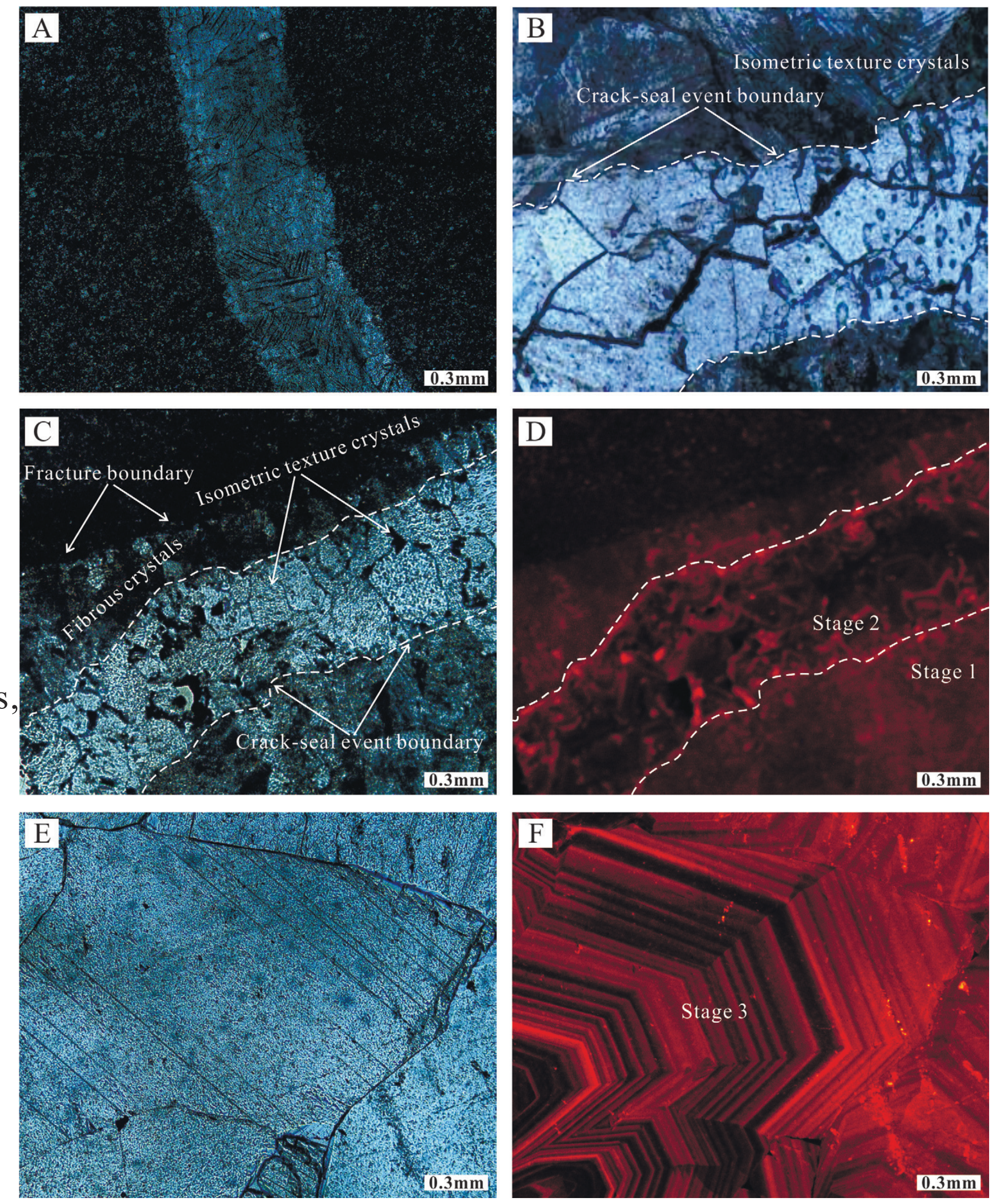


Fig. 3. Photomicrographs of calcite veins from the Shizhu synclinorium.

5. Fluid inclusion analyses of calcite veins

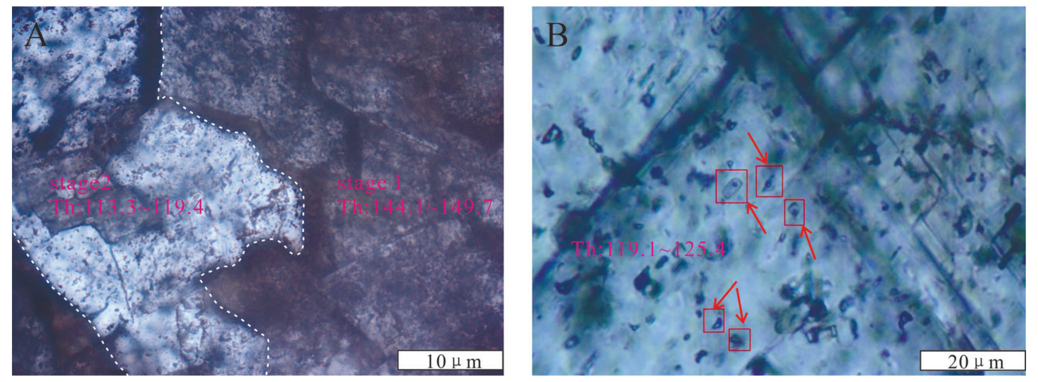
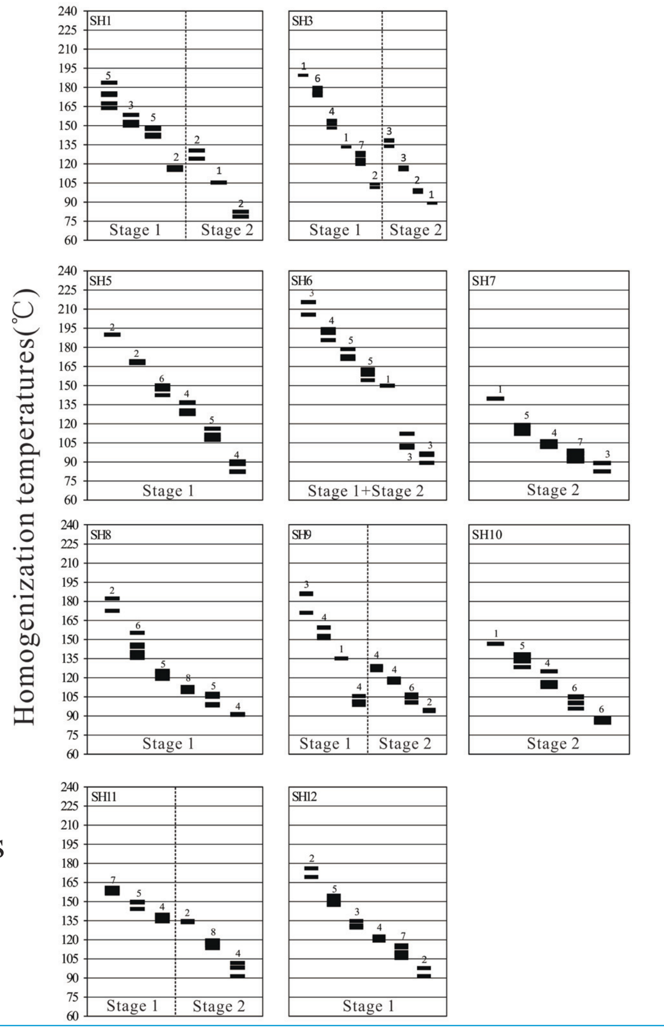


Fig. 4. Photomicrographs of fluid inclusions in calcite veins and Homogenization-temperature (Th) ranges for fluid inclusion assemblages (FIAs) in individual calcite veins.



Measured homogenization temperatures range from approximately 80 to 215°C throughout the sampled calcite veins (Fig. 4). **When Th data are correlated with the formation stages of the calcite veins (Fig. 4), we observe a decreasing Th trend of FIAs**. For example, the range in Th for crack-seal fluid inclusions in sample SH1 is from 183.6 to 78.6°C. Four sets of Stage 1 FIAs record a temperature decrease from 183.6 to 115.2°C, whereas three sets of Stage 2 FIAs show a decrease from 130.4 to 78.6°C. The other calcite veins that entirely span the fractures show similar ranges and trends of decreasing Th, summarized in Fig. 4.

6. Carbon, oxygen strontium isotopes and REE analysis of calcite veins

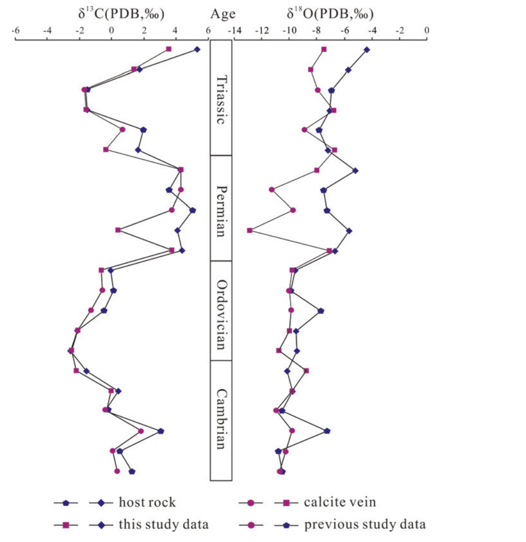


Fig. 5. Plot of carbon and oxygen isotopic data for samples plotted against the stratigraphic age of the samples.

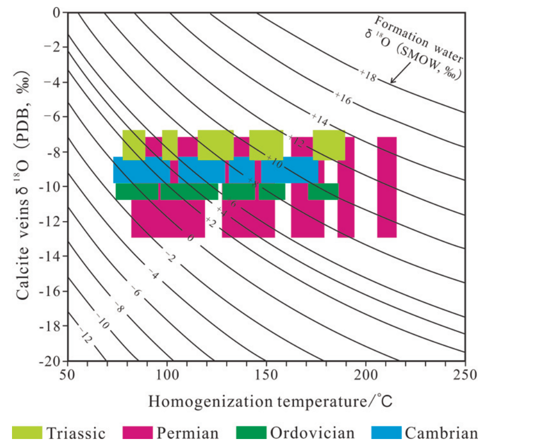


Fig. 6. Distribution of oxygen isotopic composition of the fluids precipitating the calcite veins, which were calculated from the Th obtained from aqueous fluid inclusions and the oxygen isotopic composition of the calcite veins.

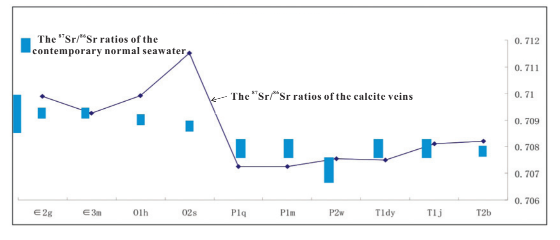


Fig. 7. the comparative diagram of the $^{87}Sr/^{86}Sr$ ratios of the calcite veins and the contemporary normal seawater

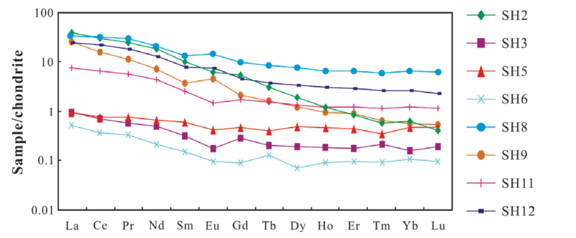


Fig. 8. Chondrite- normalized- REE patterns of representative calcite veins showing obvious enrichment in LREE relative to HREE, minor to no Ce anomalies, but obvious differences in the total REE concentrations and Eu anomalies.

- Dissolved carbon needed for the formation of calcite veins is derived from multiple sources including marine carbonates hosting the calcite veins and the degradation of organic matter.
- All the calcite veins have negative Ce anomalies, which are the typical characteristic of marine carbonate sediments, it is therefore plausible that all the calcite veins were precipitated from the marine basin fluid
- $^{87}Sr/^{86}Sr$ ratios, calculated $\delta^{18}O_{water}$ values and the distinct REE pattern simultaneously suggest that the fluids -forming calcite veins in each stratigraphic unit could be due to the involvement of fluids that originated from coeval seawater and evolved through different degrees of water/rock interaction.
- Fluids with more radiogenic $^{87}Sr/^{86}Sr$ ratios than coeval seawater and the presence of pronounced positive Eu anomalies in Lower to Middle Ordovician calcites suggest terrestrial input from upper strata mudstones and siliciclastic rocks could be involved in the precipitation of calcite.

7. Timing of vein growth and tectonic implications

Fluid inclusion analyses combined with burial and thermal history modeling indicate that the flow of various generations of brine through the carbonate formation fractures spanning a time frame from the Early Cretaceous to Eocene **(135-50Ma)**, and this time span indicates that the precipitation of calcites were related to the continuous SE-NW compression initiated by the migration of the Jiangnan-Xuefeng orogenic belt in Late Yanshanian and the long-range effect of the Early Himalayan orogeny.

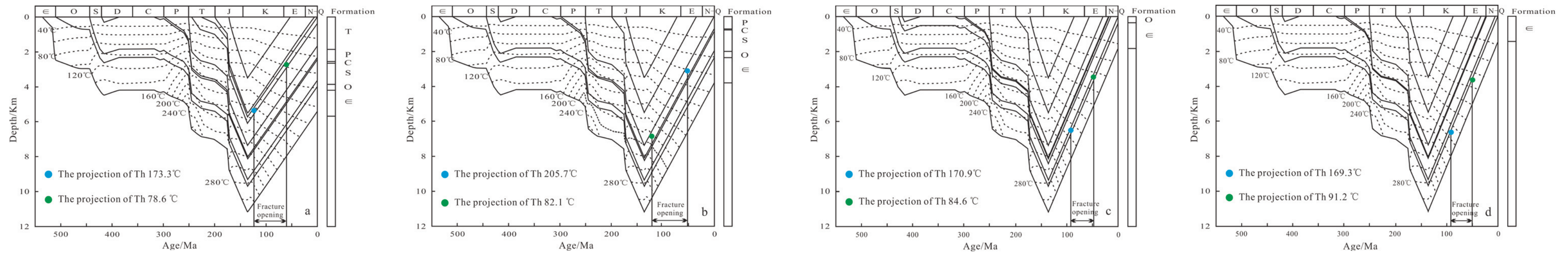


Fig. 11. Timing of fracture opening and calcite precipitation in each sampling stratum, which was determined by Th obtained from aqueous fluid inclusions in calcite veins and burial and thermal history of the study area. a, b, c and d represent the burial and thermal history of the Triassic, Permian, Ordovician and Cambrian, respectively.

8. Conclusions

The fluid inclusions and geochemical characteristic of calcite veins suggest that fluid flux associated with tectonic compression and uplift in the Shizhu synclinorium were mainly fluid flow within the same layer, and cross layer flow and influence of surface water infiltration count for little, with good petroleum preservation conditions.

References

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[2] Evans, M.A., Battles, D.A., 1999. Fluid inclusion and stable isotope analyses of veins from the central Appalachian Valley and Ridge province: implications for regional synorogenic hydrologic structure and fluid migration. Geological Society of America Bulletin 111, 1841-1860.