# Paleo-Seismic Evidence in Crystalline Rocks : Example from Precambrian Terrain of Peninsular India

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## Abstract

*The region around Wadakkancheri, which lies in the vicinity of Palghat Cauvery shear zone (Precambrian) is experiencing microseismic activity since 1989. A brittle deformation zone found in exhumed crystalline rocks in this area in which a major movement in Mid-Quaternary is identified. This fault zone consists of fracture sets with small-scale displacement and slip planes containing gouge. Detailed macroscopic and microscopic studies of this fault zone reveal distinct zones within the consolidated gouge and cross cutting relationship of fractures. Muscovite, Chlorite, Clinoptilolite and Montmorillonite are the secondary minerals associated with this fault zone. We interpret the differential enrichment of these secondary minerals in the distinct gouge zones and monomineralic fracture fills as the product of episodic fault movement. A minimum of four episodes of earthquakes/ faulting are identified at this site based on the cross cutting relationships. The occurrence of repeated earthquakes in the same fault suggests that this fault restrengthened during the long interseismic period characteristic of shield region.*


## Introduction

Mapping potentially active faults and extracting information on their past activities has become the major inputs in the seismic hazard reduction programs. Since historic and recent data are available only for a short span of time compared to the interseismic intervals geological records are increasingly used for identifying past events (Yeats *et al.*, 1997 and reference there in). Most of such paleo-seismic investigations are based either on fault scarps or soft sediment deformation structures. However, attempt was also made to identify Paleo-seismic indicators from crystalline rocks (Mawer and Williams, 1985). The present study is another effort to develop a criteria to identify paleo-seismic events from crystalline rocks.

The fault evaluated in this study is located near Desamangalam, South India (Fig1), where micro-seismic acrivity is going on since 1989 (Rajendran and Rajendran, 2004). In this paper we are discussing this fault in terms of its seismogenic character. The brittle fault-zone exposed in this area coincides with the trend of the regional structure and geomorphic anomalies (John 2003). This fault also records a major movement around 430 ka. (Rao, *et al.*, 2002).

## Geological and geomorphic setup

The study area lies in the southern flank of the 'Palghat gap' (Fig. 1), a conspicuous E-W-trending linear valley developed within the Proterozoic granulite terrain in South India (Arogyaswami, 1962; Drury *et al.*, 1984; Subramaniam and Muraleedharan, 1985; D'Cruz *et al.*, 2000). The present undulating topography of the region consists of 250-km long and 30-km wide low land ('gap') bordered by ridges and hills. The charnockitic suite of rocks (consisting of granular quartz, feldspar and hypersthene) forms the basement in the area and is characterized by well-developed foliation striking WNW-ESE with a southward dip of 30°-50° (John, 2003). A systematic joint set has also been

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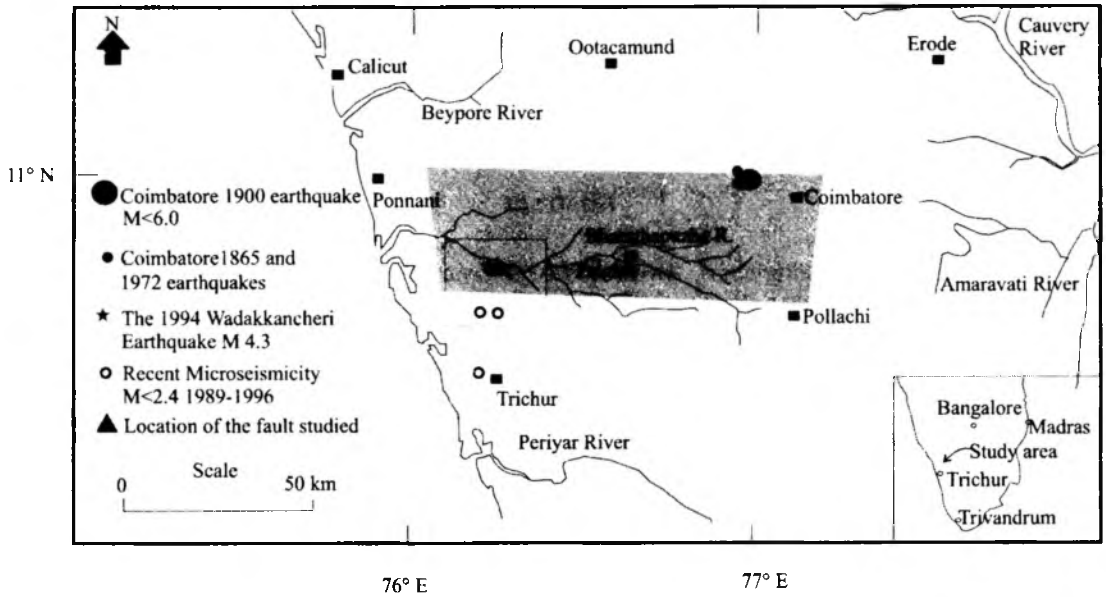


Fig.1 Map showing locations of Wadakkancheri earthquakes. Shaded portion is the Palghat Gap. The location of the fault studied is shown in triangle.

developed throughout the area, which follows the foliation trend.

## Description of the Fault

The fault zone studied is exposed in a quarry at Desamangalam along the WNW-ESE lineament (John, 2003). The fault zone is 6 m wide and coincides with the foliation that strikes WNW-ESE with a dip of 45°S (John and Rajendran 2005). The zone comprises a main fault 'F2' and two sub parallel fractures 'F1 and F3' (see Fig. 2), and can be divisible into three zones *viz.*, i) a fault core, ii) damage zone, and iii) protolith or host rock (John, 2003).

*Protolith* is the undeformed host rock surrounding fault rock and damaged zone Charnockite forms the predominant host rock in the region, and the constituent minerals include hypersthene, microcline and quartz (John, 2003). Strong foliation is observed at many outcrops and quartzo-feldspathic veins have developed in all directions including those that are parallel to foliation planes. The present fault zone seems to have been

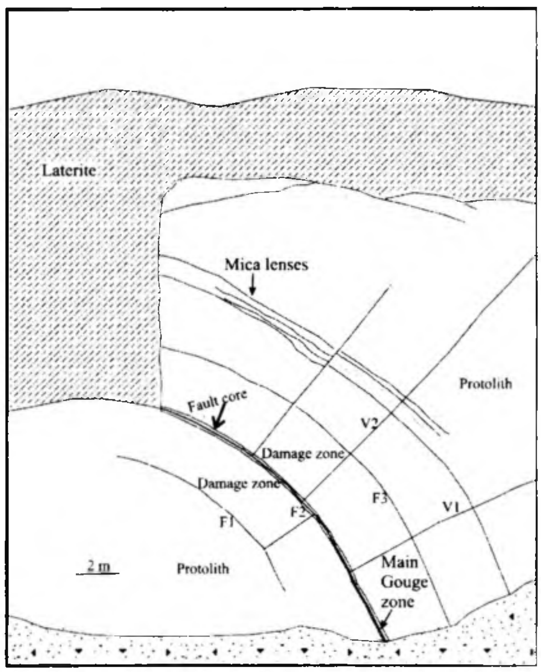


Fig.2 Sketch of the section at the quarry (DM site) showing fault zone. F1, F2 and F3 are the principal set of fractures, constituting the fault zone. V1, V2 and V3 are the dislocated veins along F2. The three distinct zones viz. fault core, damaged zone and protolith are also marked.

Table-1 Mineralogy of the host rock and gouges (Desamangalam) of successive generation based on XRD data

| Minerals | Host rock | Consolidated Gouge | | | Loose gouge |
|---|---|---|---|---|---|
| | | G1 | G2 | G3 | |
| Quartz | Abundant | Abundant | Abundant | Abundant | Common |
| Microcline | Abundant | Common | Trace | Nil | Nil |
| Plagioclase | Abundant | Abundant | Trace | Nil | Nil |
| Phlogopite | Common | Common | Trace | Nil | Nil |
| Chlorite | Nil | Trace | Minor | Common | Common |
| Muscovite | Nil | Nil | Trace | Trace | Trace |
| Montmorillonite | Nil | Nil | Nil | Trace | Common |
| Clinoptilolite | Nil | Nil | Nil | Nil | Abundant |

initiated along one of such quartzo-feldspathic vein of granitic composition.

*Damage zone* is the network of fault related subsidiary structures that bound the fault core. Fault related subsidiary structures in damaged zone include small faults, veins, fractures and cleavages (Bruhn *et al.*, 1994). Damaged zone is characterized by fractures of varying orientations. Many of these fractures are in sealed conditions. The minerals close to the gouge zone within the host rock tend to align along with the gouge zone as evident from the rotation of the mineral grains. This alignment becomes weaker within 3 cm away from the gouge zone.

*Fault core* is the structural, lithologic, and morphologic portion of a fault zone where most of the displacement is accommodated (Caine, 1996). The fault core consists of the zone demarcated as 'F2', as shown in Fig. 2, which bears clear-cut evidence of slip and gouge formation. Within the principal slip plane, the host rock appears to have been pulverized, and the original bulk fabrics completely disrupted, generating gouge. The faulting has created a 6 cm-thick gouge zone, consisting of both consolidated and unconsolidated forms. Some distinct textural and colour changes can be seen within the consolidated part of the gouge.

Detailed macroscopic examination and textural characters of the gouge layer in the fault zone under study shows that there are four distinct form of gouge. The zone adjacent to host rock shows rotated and crushed grains of quartz, mica and feldspar (denoted as G1 in Fig. 3a). The second zone is a mixture of crushed and rotated grains of quartz feldspar and mica along with greenish material (chlorite) (denoted as G2 in Figs. 3a &3b). The third zone (denoted as G3 in Fig. 3b) is separated from the second by a sharp but irregular boundary (G2 in Fig 5d). Finally, the loose gouge corresponds to the fourth zone.

**Episodic faulting**

We analysed the mineralogical association of different gouge zones (G1, G2, G3) and the host rock. Based on the mineralogical association the consolidated gouge can be distinguished as three zones similar to the macroscopic examination. The first zone is the unaltered mixture of quartz, feldspar and mica minerals (G1 in Table 1). Chlorite also occurs as the only appreciable secondary mineral in this zone. The second zone is characterized by the enrichment of chlorite and presence of sericite (G2 in Table 1). The third zone is marked by the presence of montmorillonitic clay (G3 in Table 1). The clay content of the loose gouge (G4 in Table

Table-2 Mineralogy of intra-fracture materials from different generations of fractures deduced form thin section studies and XRD Data.

| | Fracture (Fr1) | Fracture (Fr2) | Fracture (Fr3) | Fracture (Fr4) |
|---|---|---|---|---|
| Minerals | **Mainly chlorite** | **Mainly chlorite** | **Only clinoptilolite** | **montmorillonite**<br>**quartz**<br>**microcline**<br>**chlorite**<br>**clinoptilolite** |

1) is characterized by the presence of clinoptilolite.

Thin section studies reveal the fractures present in the damaged zone show cross cutting relations (Fig. 4a & 4b). We analysed the mineralogy of these fractures through petrologic and XRD analysis (Table 2). Mineralogy of intra-fracture materials from these different generations of fractures deduced form thin section studies are given in the table 2. The fractures Fr1 and Fr2 are filled with chlorite (Fig. 4a; 4b), where as the FR3 is filled with Clinoptilolite (Fig. 4b). A fourth set of fractures seems cut all these fractures but are not in sealed conditions. Based on the cross-cutting relations we calculated the different generations of faulting.

The different textural elements, mineral associations in the fault zone and overprinting of structures allow us to develop up a scenario of sequential development of fault-rocks at Desamangalm. Although, the repeated frictional sliding could result in disruption of earlier generation of deformational signatures, based on the above referenced cross cutting relations and distinct difference in deformation characters, a minimum of four episodes of faulting and gouge development and secondary mineralisation can be recognized (Fig. 5).

i) The presence of chlorite in the gouge zone G1 and cross cutting relation of fractures Fr1 indicates that these two are formed due to the first event.

ii) The morphological distinction of the gouge G2 and the cross cutting relation of Fr2 indicate that these two are formed due to the second event.

iii) The presence of Clinoptilolite in fractures Fr3 and extremely fine-grained gouge G3 represents the 3rd event.

iv) The consolidated nature of gouge, enrichment in secondary minerals and sealed nature of fractures indicate that each of the above three events is followed by fluid activity and fault sealing.

v) The loose gouge and unsealed fractures in the damaged zone corresponds to the 4th event. The fault after this last episode may be in the stage of sealing. However, unsealed fractures and unconsolidated gouge in surface conditions may not be true for the fault nature at depth.

## Conclusions

It is well known that most intraplate earthquakes occur by the reactivation of pre-existing faults (Sykes, 1978; Talwani, 1998) and the expected recurrence interval is of the order of tens of thousands of years (Crone *et al.*, 1993; Machette *et al.*, 1993; Rajendran *et al.*, 1996). However,

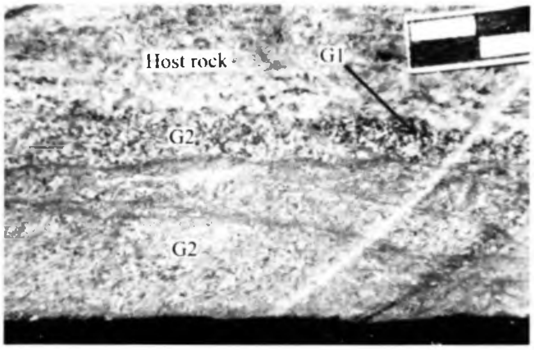


Fig. 3a Fault rock showing consolidated gouge in two zones. G1 is the isolated distinct gouge zone identified megascopically by absence of green colour (chlorite). G2 is the consolidated gouge showing crushed host rock embedded in green coloured mineral.

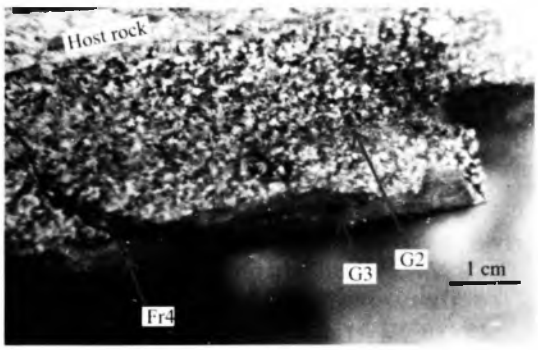


Fig. 3b Photograph showing consolidated part of gouge showing two distinct regions (G2 and G3); the fracture Fr4 cutting both the gouge zones shows no secondary mineralization.

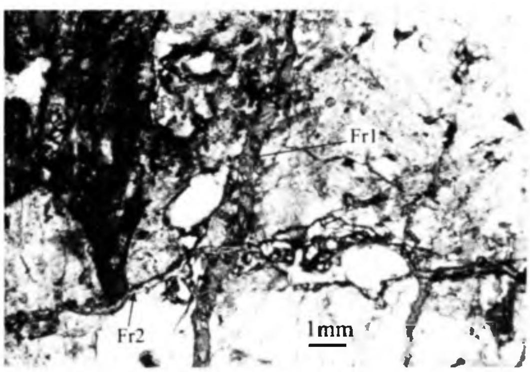


Fig. 4a Photomicrograph showing two generations of fractures (Fr1 and Fr2) in plane polarized light. Both the fractures are filled with chlorite, but in hand specimen the older fracture (Fr1) shows a dark green whereas the younger fracture (Fr2) shows a light green colour.

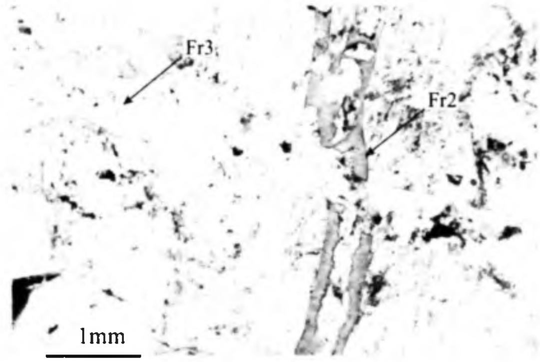


Fig. 4b Photomicrograph showing two generations of fractures (Fr2 and Fr3) in plane polarized light. Fr2 is filled with chlorite and in hand specimen it shows a dark green colour. Fr2 is filled with a white mineral clinoptilolite. It should be noted that the fracture bearing chlorite further opened up during the development of the next set of fractures facilitating the deposition of clinoptilolite.

identifying paleoseismicity in crystalline terrain is not easy. The present study suggests a criteria to identify paleoseismic events in crystalline rocks.

The fault rocks from this exhumed fault at Desamangalam represents cumulative deformation produced during different episodes of fault activity. Four episodes of deformation are identified from the fault rocks based on the crosscutting relationships. The ESR experiments on this fault have yielded an age of 430 ± 43 ka. This data suggest that this fault may be active, judging by SCR standards, where probably moderate earthquakes may recur in tens of thousands of years or hundreds of thousands of years at one source. These observations leads to the conclusion that this particular fault zone was affected by repeated stress cycling resulting in intermittent slip, separated by long intervals favouring fault sealing.

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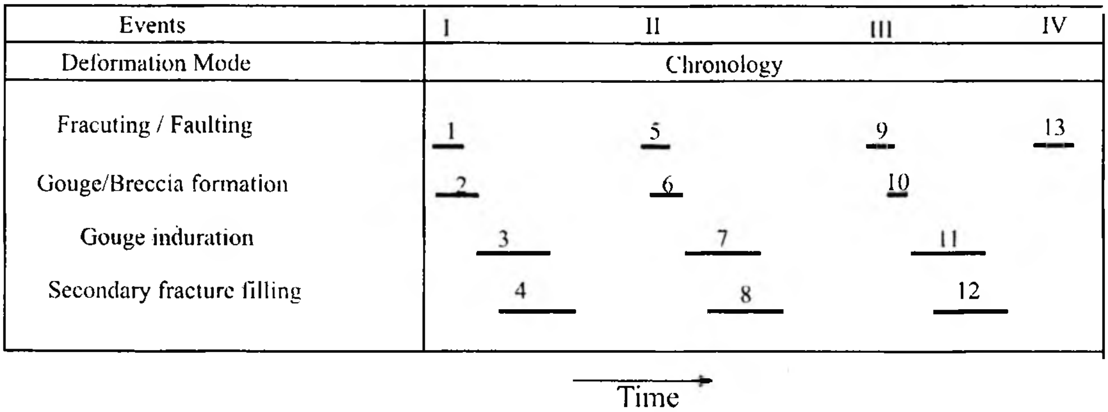


Fig. 5 Schematic diagram showing the sequential development of fault rocks by episodic faulting and fluid activity. Each faulting event is accompanied by generation of gouge and breccia which is followed by gouge induration and fault sealing aided by secondary fracture filling.

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