

# **Fracture Characterization in Contrasting Platform Carbonate Facies in Permian Limestone Outcrops, Muak Lek and Chumphae Areas, Central-Northeast Thailand\***

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## **Abstract**

A detailed fracture characterization of Saraburi Limestone outcrops was made in a Muak Lek quarry and a Chumphae quarry in order to develop a facies-based understanding of fracture distribution in the exposed Permian limestones of Thailand. This study is the first stage in developing an analogue understanding for fracture distributions in subsurface limestone reservoirs in Thailand and elsewhere. The work integrated petrographic, stable isotope determinations of outcrop samples with mapping and photographic documentation of fracture properties in the two areas. Three spectral gamma ray profiles were measured and integrated with photographic data to construct a pseudo-FMI log made along the gamma pseudowell traverse. This FMI construction assumes a microresistivity contrast is present for each fracture within the section of interest. In both quarries, there are two lithofacies associations that have distinctive fracture characteristics. Factors influencing the differences in fracture density between the facies are; grain size, bed thickness, and elastic modulus. For example, in the Muak Lek area, it clear that fracture density has a strong match to the host rock type; the fine-grained lithofacies, with their thinner beds and smaller elastic moduli, show higher fracture density and smaller apertures compared to the coarser-grained lithofacies. In contrast to Muak Lek, the Chumphae outcrop, because of pervasive diagenetic-silica cementation, shows similar fracture densities across the various lithofacies. In summary, study of outcrop analogs to fractured Permian carbonates, which constitute potential reservoirs in the subsurface of central and northeastern Thailand, show that the fracture density and fracture aperture are responses to variations in the mechanical strength. In some diagenetic situations these relationships are resolvable in a gamma log, in others they are not. This has significant implications when a gamma log is used to cluster FMI-based fracture observations in wells penetrating subsurface platform carbonates.

## **Introduction**

The understanding of the fracture characteristics with respect to deformation is at the best semi-quantitative and tied to poorly understood relationships between deformation, facies, and diagenesis. But how and why does diagenesis influence fracture characteristics? In this study, two contrasting types of fracture characteristics are discussed, both of which are controlled by the depositional facies and subsequent diagenetic evolution and are related to multiple fluid overprints.

The Saraburi Limestone outcrops in Muak Lek and Chumphae areas are considered the outcrop equivalents to the subsurface Ratburi Limestone, which constitutes the pre-Tertiary carbonate reservoir in Nang Nuan Field, Chumphon Basin. The main purpose of this study was to develop a facies-based understanding of fracture distribution in exposed Permian limestones of Thailand, as the first stage in developing an analogue understanding for fracture distributions in subsurface limestone reservoirs and elsewhere. The study area consists of two areas. These are: 1) Muak Lek in Saraburi province, Central Thailand and 2) Chumphae in Khon Kaen province located in Northeast Thailand ([Figure 1](#)). The studied outcrop of the Muak Lek area is in a small inactive quarry on the roadside of Highway 2, located at coordinates 14.6336833 latitude and 101.1694333 longitude. The studied outcrop of the Chumphae area was a much larger active quarry (cement manufacture and rock aggregate extraction), located at coordinates 16.66747 latitude and 101.83428 longitude. Both locations form part of the margin of the Khorat Plateau.

## **Methods**

Two different quarry areas in the Central Thailand were mapped and scanned in order to define the fracture characteristics of carbonate lithofacies in the study area. Outcrops were scanned photographically to create a base from which measurements of the major orientation of fractures and fracture density could be tied. In addition, several site-specific series of outcrop photos were taken in order to display the contrasts of fracture characteristics across all lithofacies.

Finally, the fracture information, based on contrasts between carbonate facies, were displayed in a series of photos that showed the different fracture characteristics of each facies, that indicated the combined effects of deformation, facies, and diagenesis. The gamma ray curve was overlain to show the wealth of fracture information not collected by conventional wireline data.

## **Results**

Both of the studied outcrops are part of the Saraburi Limestone Group that was deposited as a series of marine platform carbonates with depositional settings becoming more restricted and increasingly dolomitized upwards, (Heward et al., 2000; Baird and Bosence, 1993; Carnell and Wilson, 2004). Fusulinacean, crinoid, calcareous algal, and brachiopod fragments are the dominant grains in the Saraburi ("Ratburi") and it equivalents all over Thailand (Fontaine, 2002).

From both quarries, there are two lithofacies associations that have distinctive fracture characteristics. The crinoidal rudstone facies consistently shows lower fracture density than the adjacent siliceous mudstone-packstone facies (Figure 2). Factors influencing the differences in fracture density between the facies are; grain size, bed thickness, and elastic modulus.

The crinoidal rudstone is a coarse-grained, grain-support framework unit with a relatively low gamma signature. The siliceous mudstone-packstone facies have a much lower degree of grain support, and tends toward mud support, which reflected by the low spectral gamma ray signature. The proportion of mud, or lack of mud, along with subsequent style of cementation, contributes to strengths and ductility of these rocks in the subsurface. With all other factors constant, decreasing the grain size increases compressive and tensile strength, due to an increase in specific surface energy (a surface-to-volume function) as the grain diameter becomes smaller (Nelson, 2001). That is one possible reason why the siliceous mudstone-packstone facies (Figure 3) shows higher fracture densities than crinoidal rudstone facies. The other factor is bed thickness, the relative importance of this factor is best determined if we can compare fracture responses in different bed thicknesses in the same lithology. This could not be done in the two quarries under study. However, a plot of bed thickness versus fracture density shows us that the thinner bed have higher fracture densities than the thicker one.

The other factor controlling fracture responses is the elastic modulus of the rocks, crack damage stress increases with increasing elastic modulus (Palchik and Hatzor, 2002). The experimental work of Lézin et al., (2009) shows that texturally fine-grained carbonate rocks such as mudstone – packstone show a range of elastic moduli from 9 – 43 GPa, while the grainier carbonate rocks, such as a grainstone, show a range of measured moduli of 60 - 70 GPa. Using a Mohr diagram to illustrate stress characteristics, this can explain the fracture aperture differences in Muak Lek, that is, grainier carbonates, such as the rudstone will have bigger apertures than the finer-grained one, as discussed before, because, if subjected to the same stresses, the mudstone – packstone lithofacies would have shear fractures (microcracks) with smaller apertures as a product of the compression regime, and the rudstone would have bigger aperture as product of the tensile regime (Gross, 1995). These assumptions can not be applied to the Chumphae lithologies (Figure 4 and Figure 5) because there the calcite-filled veins are the product of an older set of deformation events and all the depositional facies are overprinted by pervasive diagenetic processes, related to both burial and uplift. The rocks are already structurally homogenized by the pervasive cementation, so the fracture aperture could not reflect the response of facies to the deformation. The elastic module of the studied crinoidal rudstones are assumed to be more texturally similar to the grainstones. So the crinoidal rudstone facies in both quarries would have a higher elastic modulus when compared to the adjacent mudstone-packstone facies, So, if subjected to the same stresses, the mudstone-packstone facies is more fractured than the crinoidal rudstone facies. But we conducted our work in the field, not the laboratory, so it is difficult to say which one of the three (grain size, bed thickness, elastic modulus) is the more significant.

The constructed FMI developed along the pseudowell traverse assumes a microresistivity contrast is present for each fracture within the section of interest. The open fractures in Muak Lek (Figure 2) would be then be picked up as a microresistivity contrast that comprise the sinusoidal line in FMI.

On the other hand, the constructed FMI of a Chumphae pseudowell does not show the same contrast in the sinusoidal fracture character between the crinoidal rudstone and siliceous wackestone-packstone B, this is because the relative mechanical strengths of the two units are much more alike. In the crinoidal rudstone the dominant cement is biogenic silica, in the rudstone it is various types of calcite. There are some differences in bed spacing between the two units, causing the slight differences seen in fracture density in outcrop, but, because the gamma log signature does not indicate lithology changes in this quarry, it is unlikely that such subtle differences would be easily recognized in the subsurface and so it would be interpreted as a total single unit with fracture density related to bed thickness.

These subtle differences both within and between the two quarries reinforce the paradigm used in interpreting fracture networks in carbonates worldwide; if there is no sinusoidal fracture trace seen in the FMI, it does not mean that a fracture does not exist in subsurface.

### **Conclusion**

Outcrop studies of fractures and lithology provide analogs to subsurface conditions and so help resolve resolution problems when integrating seismic and borehole data.

In terms of fractured reservoir characterization, fracture density is found to depend on a combination of grain size, bed thickness, and elastic modulus of the rocks. The grain size is controlled by the mud ratio, because with all other factors constant, decreasing the grain size increases compressive and tensile strength, due to an increase in specific surface energy (a surface-to-volume function) as the grain diameter becomes smaller. Differences in bed thickness also drive different responses in fracture character. Thinner beds show higher fracture density than the thicker ones. Variations in elastic modulus mean the finer grained carbonate rocks have smaller elastic modulus than coarser-grained samples, so if subjected to the same stresses, the finer grain rocks are more fractured than the coarser grained ones, so fracture density is also a function of the grain size of the deposited layer, which in the areas under study is directly related to the mud ratio.

In summary, in outcrop analogs to fractured Permian carbonates that constitute potential reservoirs in the subsurface of central and northeastern Thailand, the fracture density and fracture aperture are responses to variations in the mechanical strength. In some settings, the contrast in mechanical strength is directly indicated by changes preserved from the time of deposition. In other cases, the contrasts in mechanical strength, set up at the time of deposition, are drastically altered by subsequent diagenetic overprints.

The study of rock property contrasts between the two studied areas offers an explanation for why some lithofacies units in the subsurface are recognizable in gamma log signatures, while others are destroyed by pervasive diagenetic cementation. The loss of detail, due to diagenetic cementation, can make difficult any FMI-based fracture differentiation and interpretation program attempting to tie to depositional units in a carbonate platform succession.

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Figure 1. The study area in two different quarries in Muak Lek and Chumphae labeled by red color (modified from University of Missouri, extracted from <http://www.umsi.edu/services/govdocs/wofact2003/maps/th-map.gif>, downloaded on 20<sup>th</sup> May 2010).





Figure 2. Outcrop photograph of the crinoidal rudstone facing to N 44° E with fractures highlighted to shows the fracture density contrast.



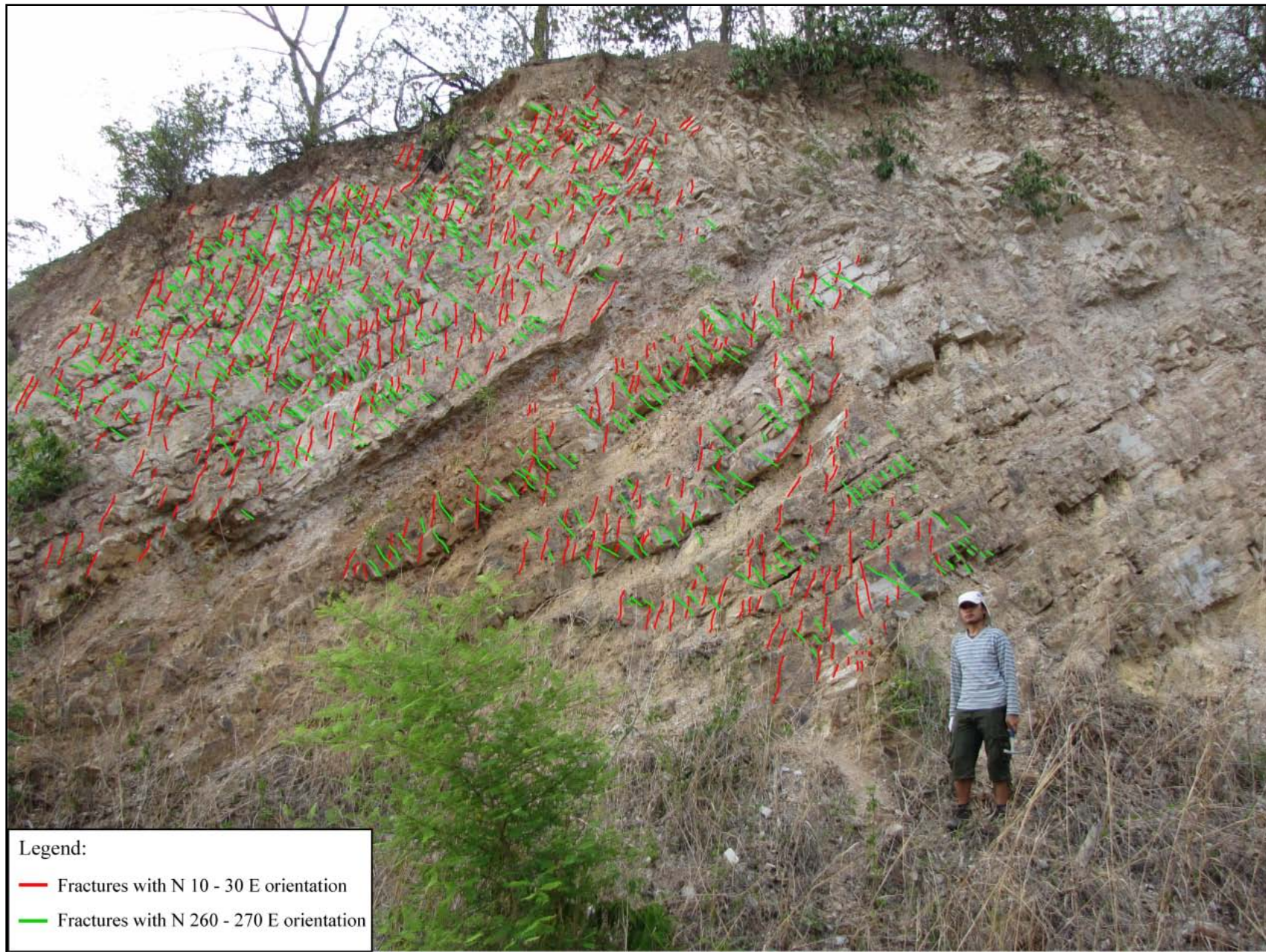


Figure 3. Outcrop photograph of detrital siliceous mudstone – spicule packstone B facing to N 330° E with fracture highlights to shows the fracture density contrast.



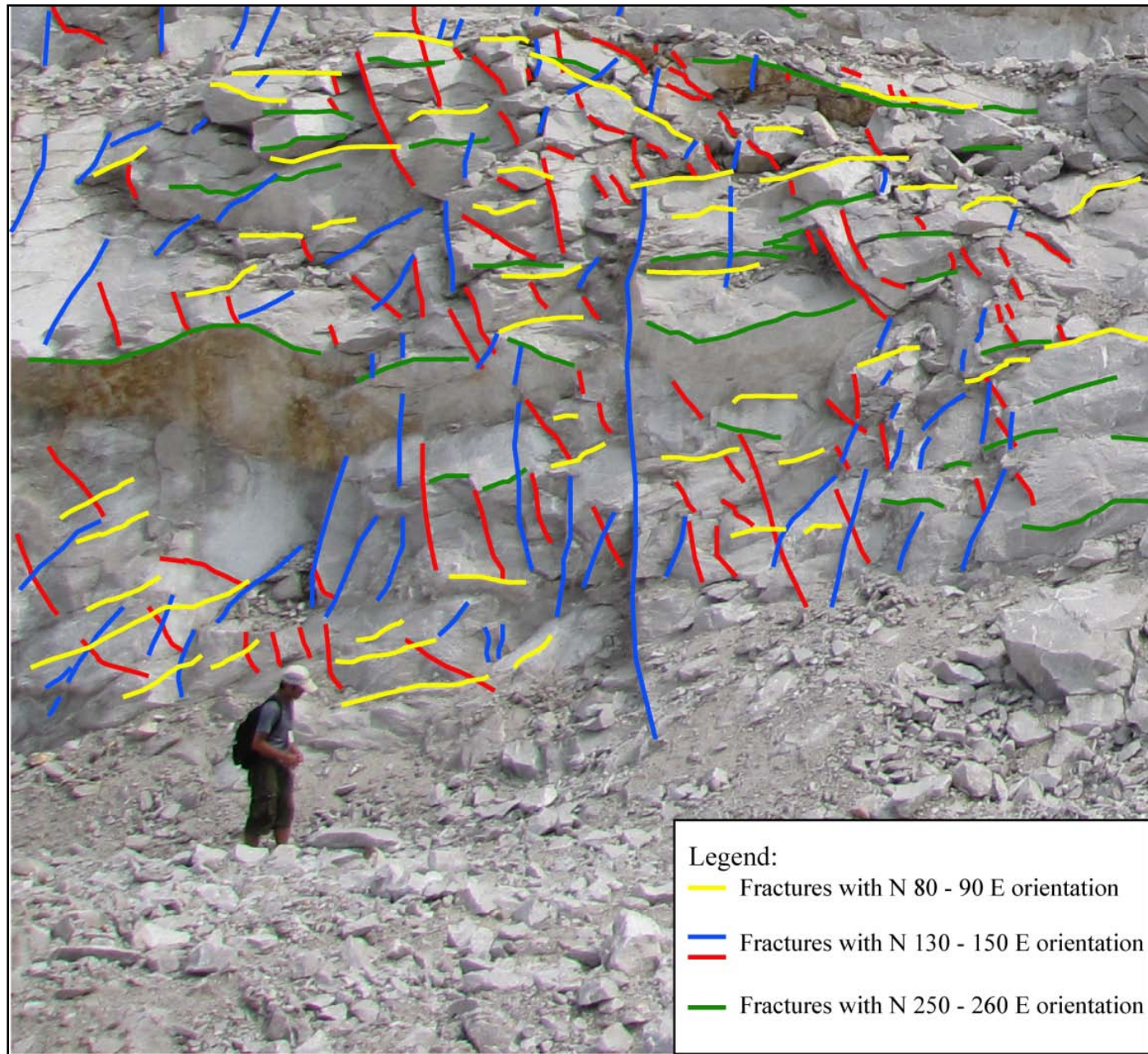


Figure 4. Outcrop photograph of crinoidal rudstone facies facing to N 355° E with fractures highlighted to shows the fracture density contrasts.



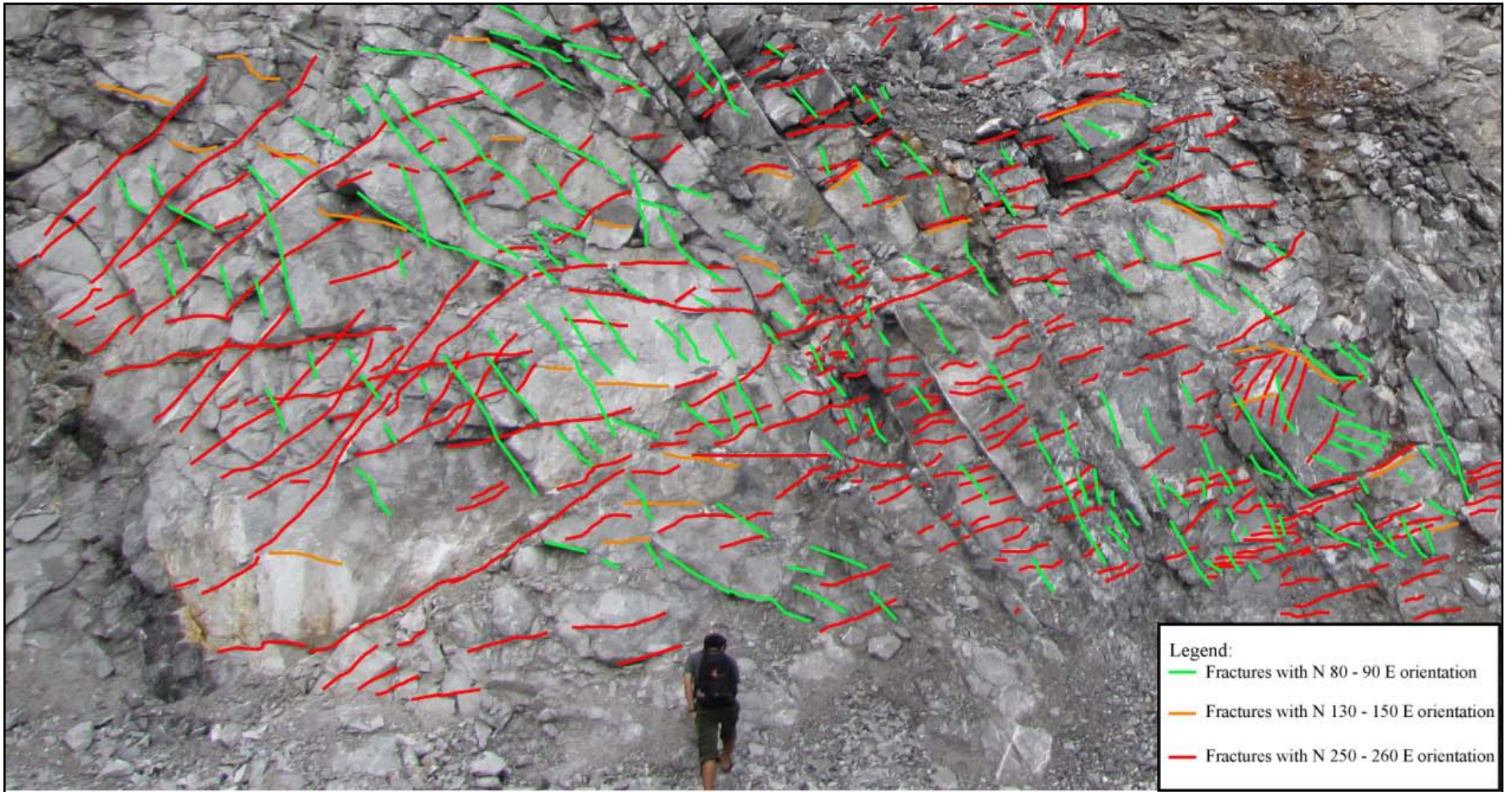


Figure 5. Outcrop photograph of biogenic siliceous wackestone – packstone facies facing to N 85° E with fracture highlighted to shows the fracture density contrasts.