# Changes in Mineralogy between wall rock and fault gouge from Marin Headlands, California


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## Abstract

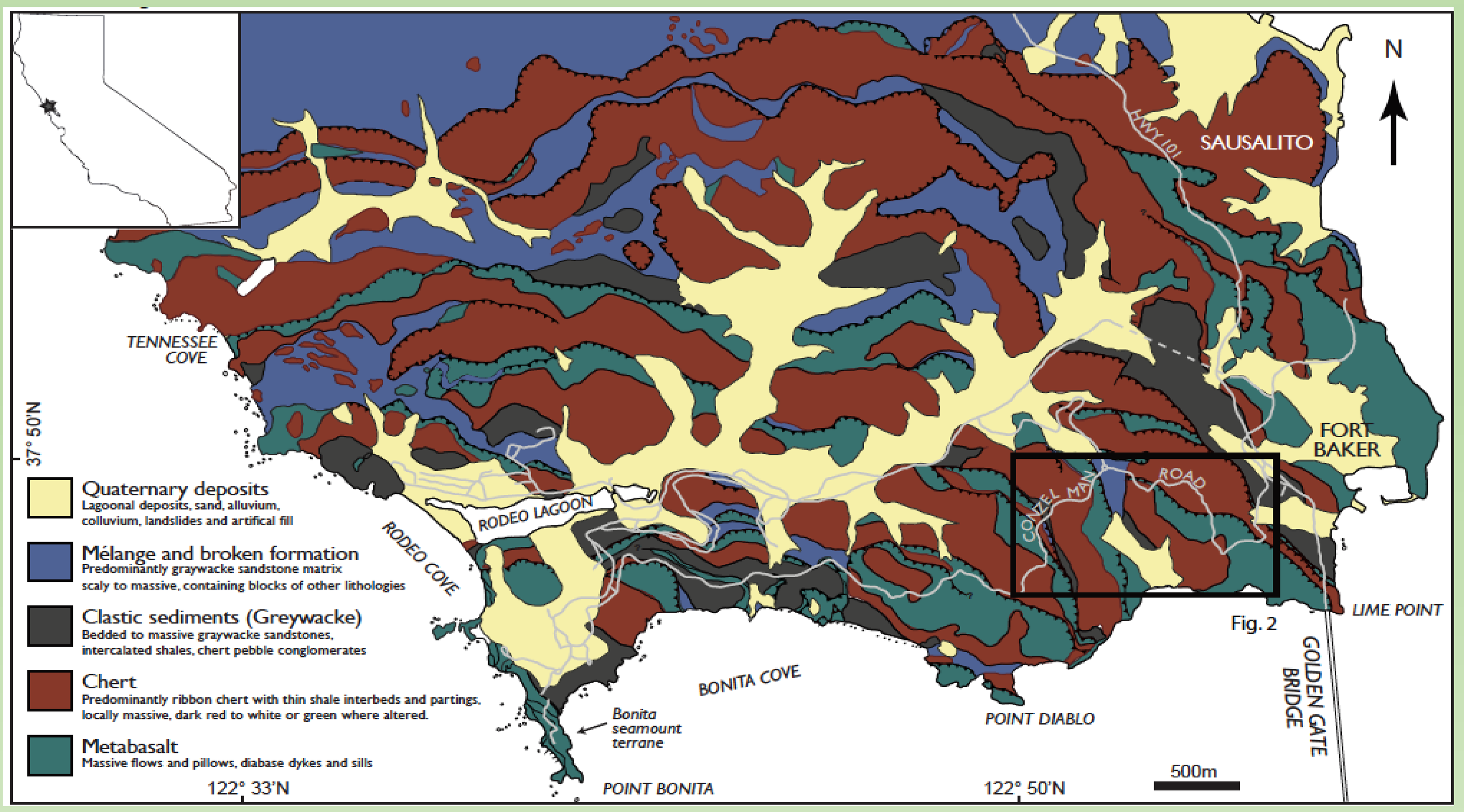
The Marin Headlands of California are located within the Franciscan Complex and have been a useful tool in understanding various structural complexities and mineralogical phase changes associated with fault zones. Mineralogy is particularly useful in constraining temperature and pressure conditions and identifying processes responsible for phase changes. The mineralogy of greywackes, radiolarian chert, and metabasalts (greenstones) were analyzed using both thin sections and XRD (X-Ray Diffraction). XRD data was completed with a Rigaku XRD Unit and Rigaku PDXL 2 Software where the peaks were best fit. From the data we were able to determine that the Marin Headlands fault was active at ~200-250°C based on the presence of pumpellyite and chlorite. This was evident in both thin section analysis and XRD data. The mineralogy of the samples indicates mid to low range of metamorphic basalt, greywackes and chert. Hopefully the discoveries in this research will help to understand the mineralogy behind these rocks which can be applied to areas of a similar mineralogical make-up and geologic setting.


## Introduction

Rocks are made up of a wide variety of minerals, which have different strengths and frictional properties. The changes in mineralogy between wall rock and fault gouge in earthquake-generating fault zones, such as the Marin Headlands in California, experience deformation and alteration of mineralogy which affect their strength. These changes can have major effects on the earthquake cycle. We were able to constrain the mineralogy by using X-Ray Diffraction (XRD) and thin section analysis. In addition we tried to understand the processes that were active during faulting to cause these mineralogical changes (alteration, solution mass transfer, dissolution, fluid-rock interaction, etc.), and how the microstructures in the fault gouge samples correspond to the mineralogy, e.g. can syn-kinematic mineral assemblages be identified and the conditions (T/P/fluid) during faulting for each fault. Earthquakes occur within both continental and oceanic plates, but the specific mineral changes experienced by rocks typical pf oceanic plates have not been characterized.

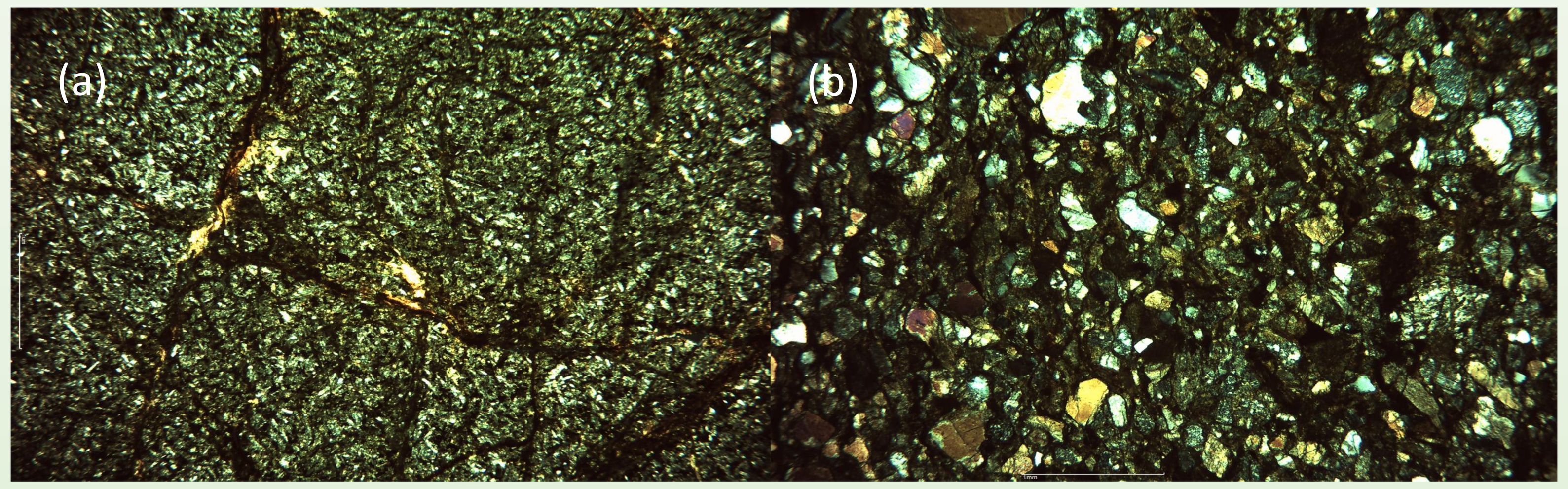
## Geologic Setting

The Marin Headlands of California is about 8km in length (E-W) and 4km wide (N-S) (Wahrhaftig, 1984). It is part of the Franciscan Complex which is composed of ten S to SW-dipping pieces of Mesozoic ocean floor (Wahrhaftig, 1984). The rocks of the Marin Headlands occur in large imbricate sheets. Each sheet is composed of pillow basalts (greenstones), red ribbon radiolarian chert from the Jurassic and Cretaceous and a thick bedded turbitditic greywacke and lithologic unit varies from 250-300m thick, (Wahrhaftig, 1984). About 20-25 percent of the exposed rock in the Marin Headlands is basalt which consists of coherent pillow basalt from the mid-ocean ridge (MORB), 50 percent of the Marin Headlands are underlain by chert and he remaining 25 percent of the Marin Headlands consists of clastic rocks—more specifically, the greywackes.



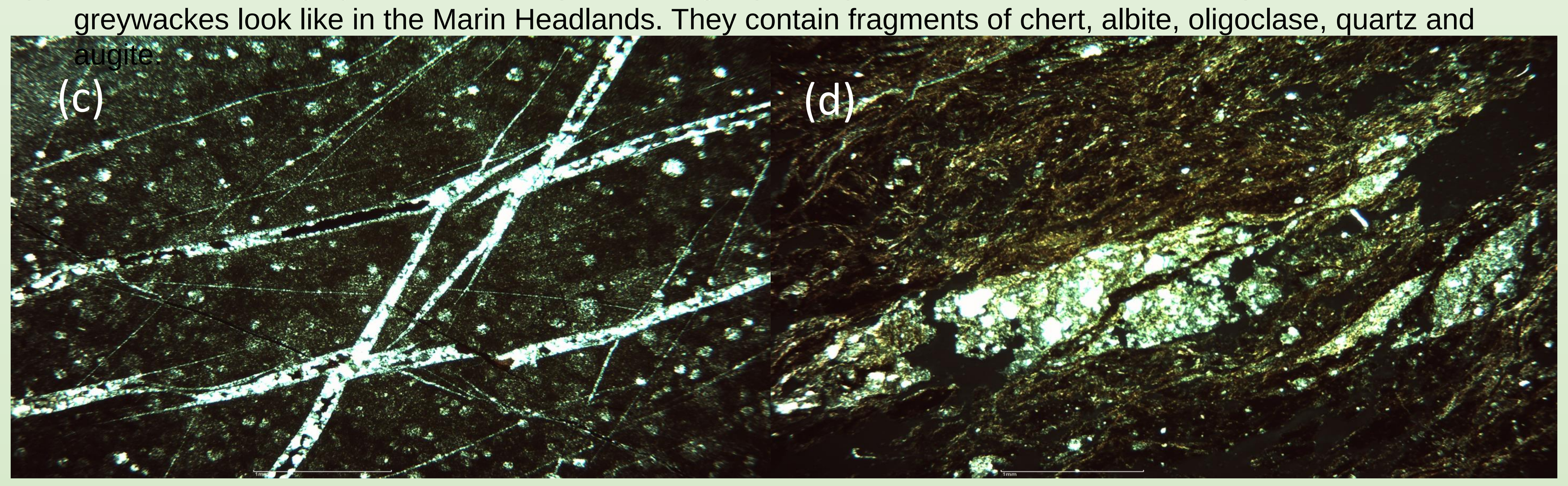

This figure is of the lithology of the Marin Headlands. (Regalla et al, in press)

## Results



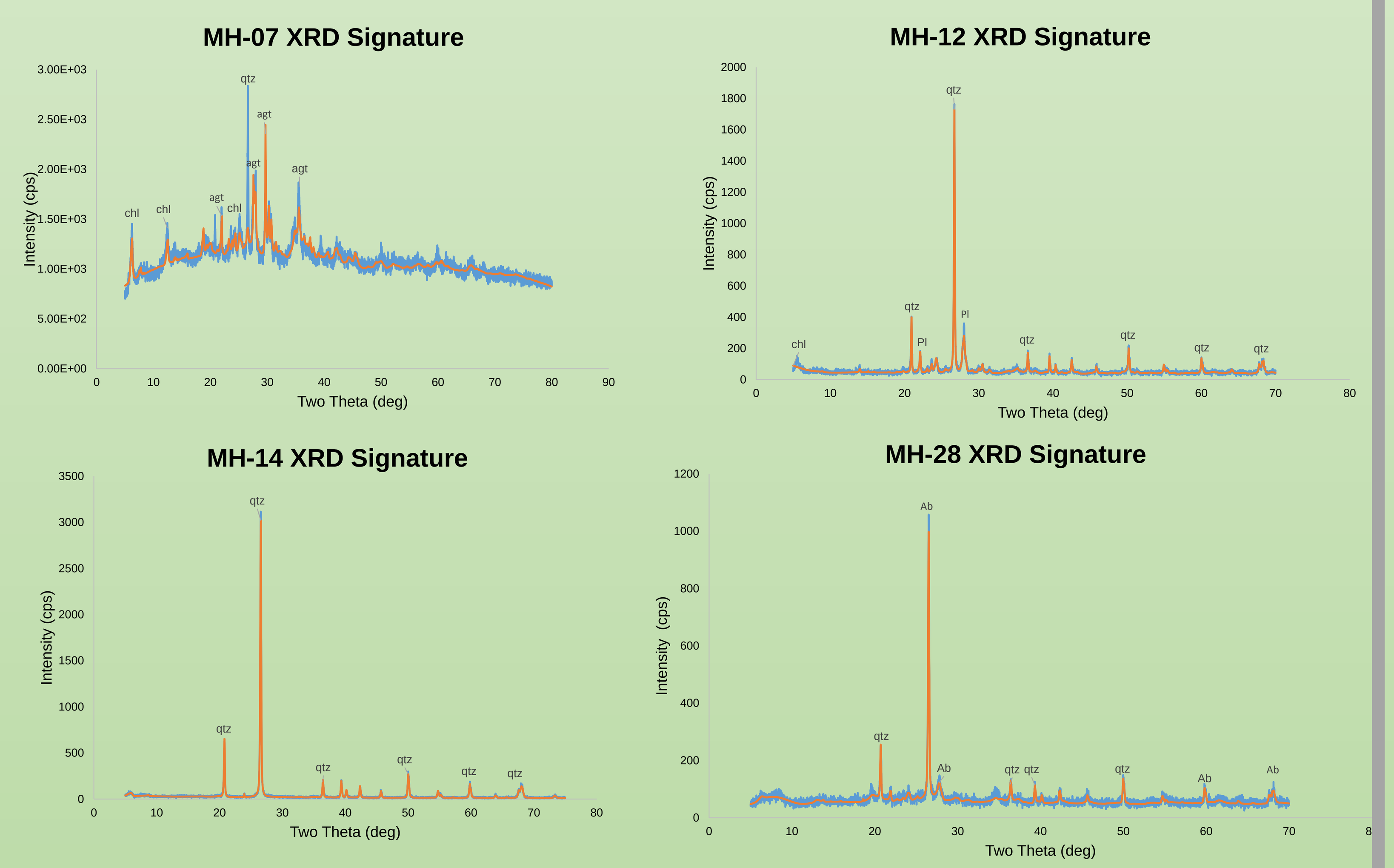

(a) Thin section of a greenstone in cross-polarized light (MH-07). This samples provides an examples of what most greenstones found in this area look like with white plagioclase laths, black pyroxenes, and augite grains.

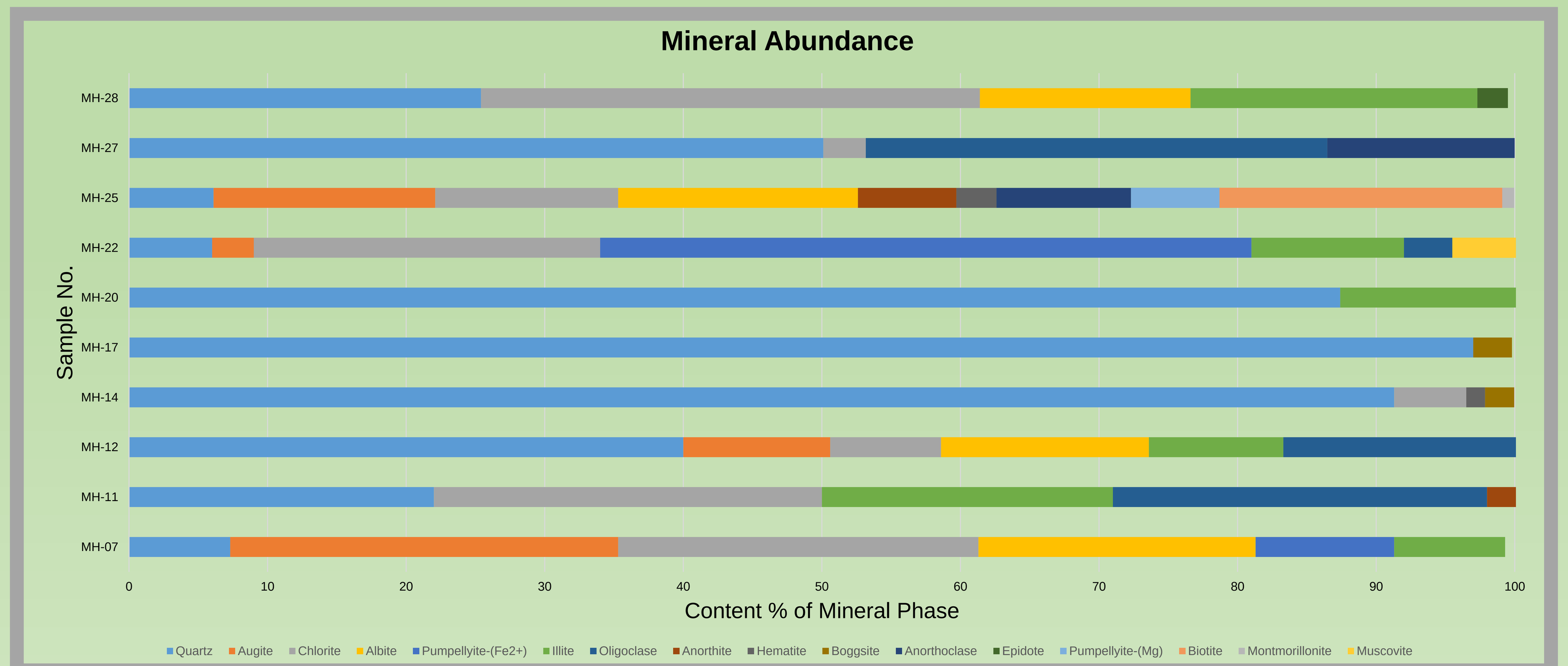
(b) Thin section of a greywacke in cross-polarized light (MH-12). This is another classic example of what greywackes look like in the Marin Headlands. They contain fragments of chert, albite, oligoclase, quartz and augite.




(c) Thin section of chert in cross-polarized light (MH-14). This is a classic example of the red ribbon chert found in the Marin Headlands. The white circles are silicious Radiolaria, the veins are filled with polycryslline quartz and the background matrix is composed of a microcrystalline quartz (chert).

(d) Thin section of a scaly black fabric in cross-polarized light (MH-28). It is one of the three fault gouge samples. It also contains porphyroclasts that that exhibit a sense of shear and contain quartz, albite, epidote and augite.




This figure contains all of the samples abundance of minerals out of 100 percent. It serves as a visual to compare their compositions.

## Methods

For XRD (X-Ray Diffraction) analysis, the samples were either ground in McCrone micronizing mill or Spex mill depending on the amount of clay in the rock. More clay rich samples were hammered into smaller pieces and gently brushed into a grinding jar with corundum grinding elements through a 0.5 mm sieve. About 7 ml of distilled water was poured into the jar to wash the particles between the corundum grinding elements. The rocks were ground more or less for four minutes. The slurry was then poured onto a watch glass and placed into a drying oven at 65°F until dry. The sample was then ground using a mortar and pestle and the powder was put into randomly oriented powder mounts (backpacked) and were tested for bulk analysis. The greenstones were put into a Spex mill and ground to a fine powder for about ten minutes. They were then transferred to a randomly oriented powder mount and tested for bulk analysis.

Thin section analysis coincided the XRD data. Most of the rocks for this study were too fragile to be cut by a rock saw. Many of them had to be put in epoxy and then cut. Samples MH-07, MH-12, MH-14, MH-20, MH-22, MH-25, MH-27, and MH-28 were analyzed in both cross polarized and plane polarized light at magnifications of 10x, 20x, 50x and 100x. Some of the thin sections were difficult to analyze due to their fine grained, metamorphic nature. The mineralogy was determined through evidence of cleavage, twinning, pleochroism, relief, extinction angles and in some cases color. Using both methods of XRD and thin section analysis gave mineralogical confirmation between samples

## Interpretations

The Marin Headlands is an underplated accretionary wedge that has stacked layer up layer of metamorphosed rocks for millions of years. Due to the nature of the Marin Headlands formation, we are able to take an excellent look into the mineralogy of the area and begin to determine the pressure and temperature constraints responsible. The presence of chlorite and pumpellyite indicates that the thrust responsible for creating the Marin Headlands was active at ~200-250°C (Meneghini and Moore, 2007). All of the samples contain various amounts of chlorite. This is evident in both the XRD data and in thin section analysis. Many of the thin sections are covered in a chlorite overgrowth, which means chlorite is an alteration mineral. The chlorite was not in the original mineral assemblage. Two stages of alteration and very low grade metamorphism could be responsible for the wide range distribution of chlorite in these samples (Kameda et al, 2011).

The thin section analysis and XRD data allowed for a narrow window of possibilities for the fault gouge and wall rock composition.

Most of the rocks are made of the similar minerals because they all come from the Marin Headlands. The mineralogy of the samples indicates mid to low range of metamorphic basalt, greywackes and chert. The metabasalts are defined by high peaks of quartz, albite and chlorite. The greywackes have a larger variety in peaks as they are a melange of different rock fragments from the surrounding area. The greywackes tend to contain quartz, feldspar and clays, while the chert mainly contains quartz peaks with accessory minerals in very small concentrations.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