Preliminary observations of M_w 5.1 Sparta (North Carolina) surface deformation – the first documented Mw 5 instrumental earthquake surface rupture in Eastern USA

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Introduction

A moderate M_w 5.1 earthquake occurred near Sparta in North Carolina on 08/09/2020 shaking the Blue Ridge Mountains with a maximum intensity of VII. The earthquake was preceded by 8 foreshocks with Mw 1.8 to 2.6, some were felt and heard. A total of 525 structures were damaged, 60 of them with major damage (≥40% of the structure was a total loss). 25 homes were considered uninhabitable and 19 were lost. There was some minor road damage, and a water pipe was broken. Although infrequent, this region is subjected to moderate seismicity. This is the strongest earthquake in North Carolina since the 1916 M 5.2 that had an epicenter~170 km to the SW. Despite a moderate magnitude a surface rupture with cm displacements was generated and recognized for about 3 km.

Seismic and Remote Sensing Data

The location of the hypocenter and depths by the USGS were variable – 3 different depths were estimated namely 11.5, 7.8 and 3.0 km with a focal mechanism indicating reverse-oblique. Analysis of the nodal planes can slightly differ although being comparable: one plane trends 300 dipping NE and the other trends ~170 dipping SW (Fig.1). Preliminary analysis of interferograms of Sentinel 1 & 1B (unwrapped) indicate a likely deformation zone trending 150-160 with relative uplift to the south and subsidence to the north up to 20 mm (Fig 2.). This pattern is consistent with a reverse motion associated with the nodal plane trending ~170 dipping SW. The interferograms also allows to infer a surface deformation zone with a length up to 3 km.

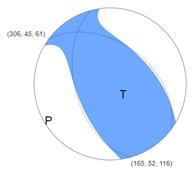


Figure 1: Preferred USGS focal mechanism with a depth of 3 km.

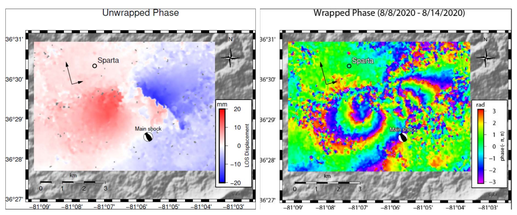
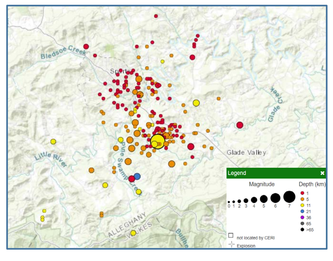


Figure 2: Interferograms Sentinel-1A for the reference scene (8/8) and Sentinel-1B for the repeat (8/14) done by Eric Szymanski (University of Michigan).



A couple of days after the main shock, 4 temporary stations were installed by the CERI (UMemphis), in an effort to record and characterize the aftershock sequence. Most of the events have magnitudes <2 and shallow depth (Fig.3).

Figure 3: Seismicity in the Sparta area including foreshocks and aftershocks, taken from CERI website.

Figure 4: Views facing south. A- Buckling of the road pavement and water pipe rupture in the River Edge road: the water flowed into the footwall. Photo taken immediately after the earthquake by a resident. The damage was repaired 2-3 hours after the event. B- The road was repaired and flatten. Note the small scarp in the side of road, propagating to the east.

Field Surveys- Surface Rupture Recognition

Immediately after the earthquake a team from NCSU, USGS, NCGS and UNC initiated the field surveys. Roads and parking lots pavements were deformed through fissures/cracks and/or folding at specific locations that work as starting points to track deformation. Frequently, surface deformation evidence was only a few cm and very subtle. In addition, the Sparta area is strongly vegetated and following subtle surface deformation evidence revealed to be challenging.

Evidence of deformation were better exposed at two main sites: an industrial park at Greenway Drive (GD) and River Edge (RE) where the road and a water pipe were broken during the event (Figs. 4 & 5).

At GD, several fractures/steps disposed in a right stepping en echelon were present along a 200 m transect. Some of these features had vertical deformation generating small scarps frequently associated with folding. In some cases, the scarp was subdivided in two (Fig. 5B. The maximum vertical deformation is ~20 cm at a single scarp (Fig. 5A), but generally ranges from 8 to 12 cm or even less, especially if towards the end of individual segments.

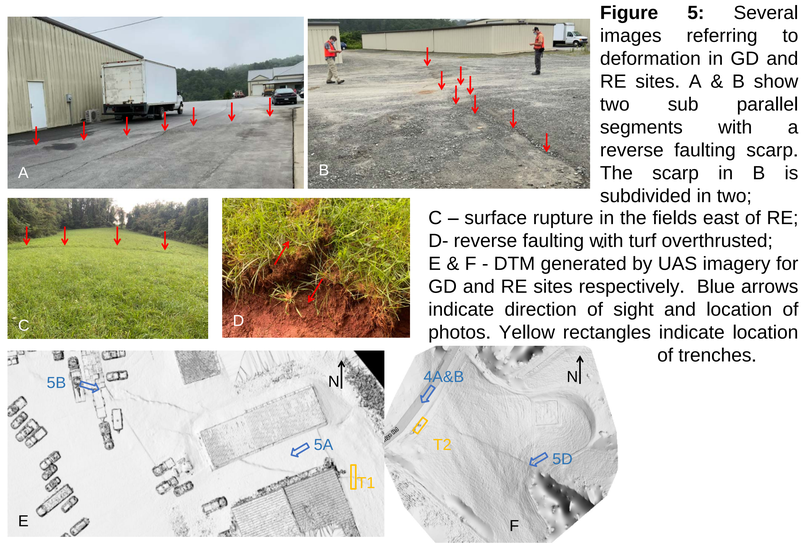


Figure 5: Several images referring to deformation in GD and RE sites. A & B show two sub parallel segments with a reverse faulting scarp. The scarp in B is subdivided in two; C – surface rupture in the fields east of RE; D- reverse faulting with turf overthrusted; E & F - DTM generated by UAS imagery for GD and RE sites respectively. Blue arrows indicate direction of sight and location of photos. Yellow rectangles indicate location of trenches.

At RE, the surface deformation is expressed mostly by a single linear feature, continuous for about 1100 m with a vertical deformation not higher than ~8 cm. This segment ends close to Chesnutt Grove Church Road. The surface rupture at both locations trends ~100° and they are aligned. So far, a prolongation with the same direction either to the W or E locations was not found, thus making a total of 2200 m surface rupture length.

Trenching

To investigate the sub-surface deformation we excavated two trenches perpendicularly to the surface rupture at GD (T1) and RE (T2). Location is provided in Fig 5E & 5F.

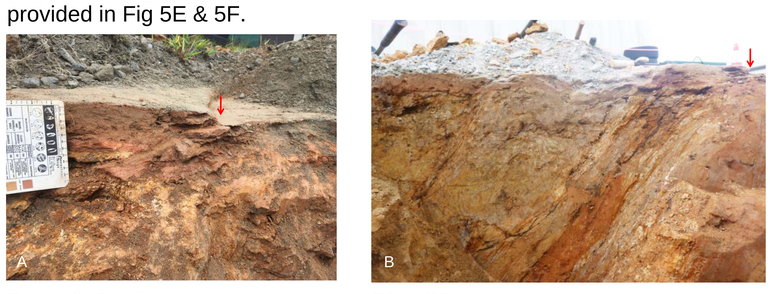


Figure 6: Detail of southern wall in trench T1 at GD, red arrow indicates surface rupture location, identical in both photos. A- surface rupture expressed by faulting with displacement of Q stratified layers; B- the surficial deformation gets rooted in a ~50° south dipping pre-existing fabric in the Paleozoic Ashe Metamorphic Suite.

T1 Trench

T1 trench was dug in the termination of one segment and revealed evidence of reverse faulting in its upper few tens of centimeters of the trench, displacing horizontally-bedded Quaternary clays and sands ~10 cm along a fault plane dipping ~19° to the S with a vertical offset of ~4 cm (Fig 6A). It roots into saprolite, into a fabric dipping ~50° to the south (Fig. 6B) that has evidence of brittle and ductile deformation of unknown age.

T2 Trench

T2 trench was dug across a small scarp in the continuation of RE water pipe and road break. Here a colluvium unit "(dark brown) overlays a likely slope deposit (brown-orange) that gradually evolves to a saprolite (transition difficult to recognize). No bedrock is exposed. Unlike T1, no faulting was recognized, but rather a gentle flexure, despite the 8 cm high scarp recognized. Although suggestions of a fault plane were recognized in the trench, no displacement of markers or recognition of a unarguable fault plane were found (Fig. 7).

Figure 7: Trench T2 southern wall. A- an apparent fault plane indicated normal faulting, not consistent with a expected reverse component; B- the feature was excavated and not corroborated; C- the deformation expresses by surface folding and a slight "bump" in the brown-orange unit.

Further evidence

We recently recognize surface deformation near US21, SE of the termination of the known surface rupture. Here a likely surface rupture trending 118°, is express by a reverse scarp ~8 cm high. Extensional features with oblique left-lateral are present in the hanging wall. Further investigation is needed, since the pavement presents evidences of older deformation. If confirmed to be associated to the Mw 5.1 event, this extends the rupture to the SE, and a length close to ~3 km (Fig. 8).

Figure 8: Deformation near the US21. A- reverse scarp with extensional features in the hanging wall; B- 8 cm high scarp; C- compression feature with pavement overthrusting moss.

Conclusion

The 08/09/2020 moderate Mw 5.1 earthquake in Sparta, NC had a surface rupture. It expresses by reverse scarps and fissures with cm displacements, along a narrow and very localized deformation zone. Trenching at two locations suggests that surface faulting is controlled by bedrock proximity to the surface and existence of previous discontinuities. When sediment and weathered saprolite are predominant, deformation seems to be accommodated by flexure.

It is still unknown what structure triggered the earthquake and generated the surface deformation. The segments 100° trend are being interpreted as a reactivated fabric now acting as a fragile young structure (Little River Fault), but further studies need to be conducted. Preliminary compilation of present data, suggests a consistency between field observations and InSAR analysis (Fig.9).

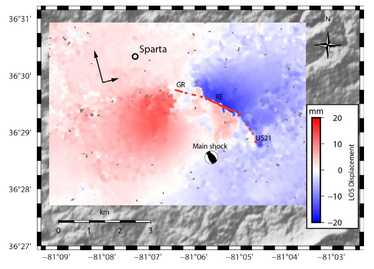


Figure 9: Unwrapped Interferograms, overlapped by the surface rupture mapping in red.

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