A potential impact site in the Sahara Desert, Niger, based on remote sensing evidence

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Introduction:

Remote sensing investigations of West Africa reveal a roughly 10 km in diameter, circular feature in north-central Niger. This study attempts to provide evidence that it is a possible impact structure. Utilizing satellite images accessed through Google Earth, a circular feature, termed the Alleged Impact Site (AIS), was observed at 21°21'14.56"N Latitude and 9° 8'32.24"E Longitude (Fig. 1). According to published geologic maps, the AIS is located within Early Devonian marine sedimentary strata [1, 2, & 3]. About 100 km to the south is a world-class suite of anorogenic ring plutons located in the centrally exposed Precambrian basement of the Aïr Massif [4]. These 399 to 443 Ma plutons appear similar in structure to the AIS [4, 5, & 6].

Without the ability to conduct field investigations, remote sensing is often necessary as an initial method for ruling out some of the processes potentially responsible for the AIS structure. The first task is to determine whether or not the AIS is related to the prominent ring plutons or is composed of sedimentary rock, as was previously mapped. Next, other geological processes, such as structural doming or evaporite diapirism can be addressed by inspection of the previous geological mapping and lithologic descriptions. Confirmation of the AIS as an impact structure will untimately be done from field mapping and petrologic/petrographic analysis, though remote sensing of this currently inaccessible site provides critical initial reconnaissance data.

Methods:

Classification techniques using the ENVI software platform were applied to 10-20 m per pixel resolution datasets from the Sentinel 2A satellite to determine the relative composition of the AIS host rock compared to the ring plutons of the Aïr Massif and sedimentary rock outcrops in the region. Level 1-C processed data were accessed from both the USGS (United States Geological Survey) Earth Explorer Website and the European Space Agency’s (ESA) Copernicus Open Access Hub website. Scenes were checked for passing quality inspections, minimal cloud cover of <2.3%, and included a range of dates to maintain data quality.

Spectral profile plots were created by selecting pixels for each endmember rock type in the Aïr region and compared to the rocks within the AIS (Fig. 2).

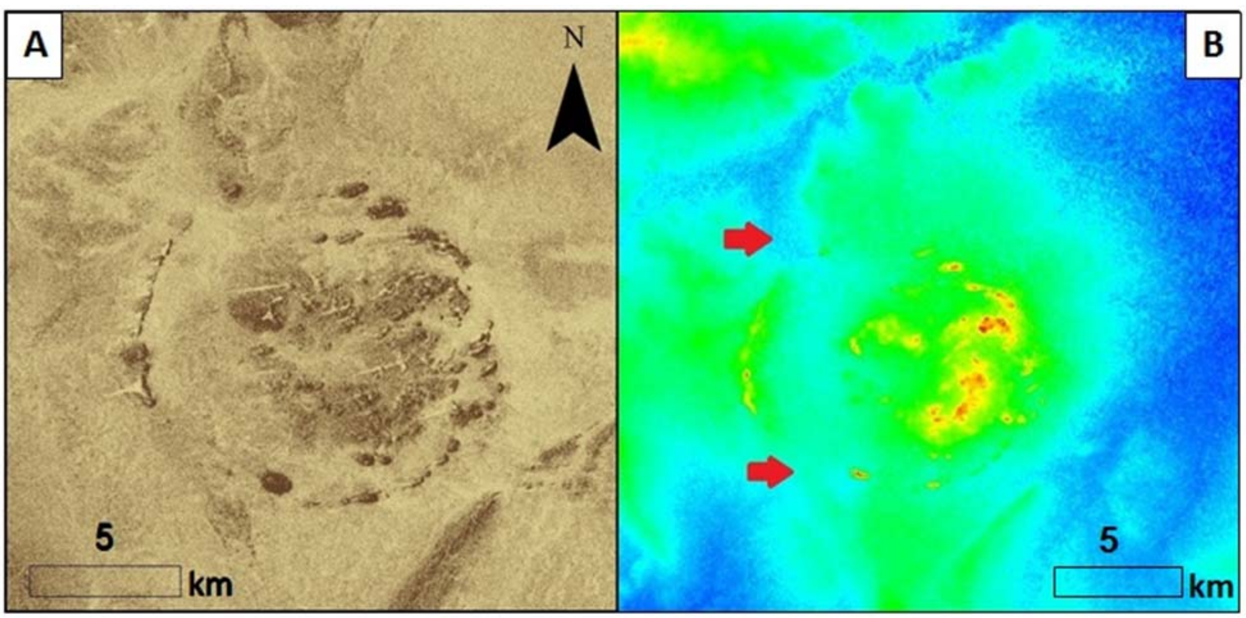

Figure 1: Radar images of the AIS. **(A)** Sentinel 1A composite polar image reveals additional details of the outcrops within the rim. **(B)** SRTM image enhanced with 200 raster color slices from the grayscale image. An ancient drainage channel, denoted by the red arrows, explains eroded sections of the outer ring and inner outcrops.

Some pixels remain unclassified, but this is expected with the strict ~2.86° angle of discrimination. All other endmembers appear to be properly classified. Pixels were selected for a range of reflectance values to include full sun and shaded outcrop and averaged to produce a single spectral profile. These plots reveal clear distinction between endmembers and allow for classification of most pixels within a scene (Fig. 2). Classification using Sentinel 2A datasets allows for more accurate identification of outcrop and land cover types over older satellite datasets.

The distinction in endmembers between the quantified spectra for Sentinel 2A data provided the confidence for a definitive classification to be made. The Spectral Angle Mapper classification technique was applied to the scene containing the AIS as well as two stitched scenes that comprised the majority of the Aïr Massif. To improve the confidence of the classification, each endmember was averaged from 500-1000 pixels and a higher discrimination of 1/20th radian or ~2.86° was used between angles for a spectral match.

Geological maps and unit descriptions by Black [1], Zanguina et al. [2], and Schlüter [3] were used to assess the unit lithologies and structures near the AIS.

Results and Discussion:

The Sentinel 2A classifications indicate that the AIS shares spectral characteristics with nearby outcrops of sedimentary rock and not with igneous rocks exposed in the Aïr Massif. A wide variety of igneous rock types occur within and around Aïr Massif, and these were used to define the spectra of the igneous rocks. While it is possible that the classification did not include some igneous compositions from the Aïr Massif, the excellent match between the AIS and the nearby sedimentary rocks supports the geological mapping of Black [1] who showed the Devonian Idekel sandstone and the Late Proterozoic, weakly-metamorphosed molasse of the Proche-Tenere Formation at the AIS site. In addition, there are no mapped folds that could be related to a structural dome, but field investigations would confirm this.

An extrusive volcanic origin is also unlikely. Extrusive volcanic rocks within the Aïr Massif were either unclassified or were classified as plutonic igneous rock. Additionally, none of the extrusive formations in the region approach the size of the AIS, they are known to only occur in the southern Aïr Massif, and all of them display a considerable drape of volcanic rocks that is not present around the AIS.

If a domal pluton, such as a laccolith, or salt diapir exists below the surface at the AIS, then this could also explain uplift and subsequent erosion of sedimentary strata in a concentric shape. Absent in published lithologic descriptions, however, is evidence of diapiric evaporite deposits that could produce the observed circular morphologies or floored igneous intrusions. The AIS is also similar in appearance to the Chandragup mud volcanoes in Pakistan [7 & 8]. But mud volcanoes are also not known to exist within the rock formations in this region of the Sahara.

The morphology and classifications of the AIS supports the possibility of it being an impact. The AIS is in line with other confirmed African impact sites including the Aorounga Crater and the Gweni-Fada Impact Crater. Both of these sites have an estimated age of 345 Ma or younger [9 & 10]. These structures, if related to the AIS, may represent an impact crater chain from a single event and would indicate the AIS formed at least 48 m.y. after the deposition of its host rock.

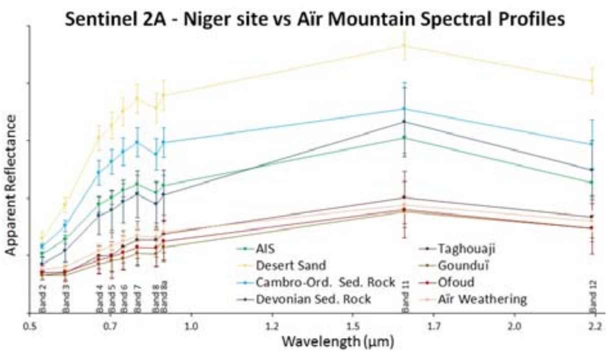

Figure 2: Spectral profile plots show the relative reflectance values of various rock types found in the Aïr region. Igneous plutons and their weathering products are grouped at the bottom with lower refelctance values while desert sand, sedimentary rocks, and the AIS show higher reflectance and display similarities between peaks of different wavelengths.

References: [1] Black R. (1967) *Carte Geologique De Reconnaissance: Massif De L'Air*. S.l.: Bureau De Recherches Geologiques Et Minieres. [2] Zanguina M. et al. (1998) Journal of Petroleum Geology, 21(1), 83-103. [3] Schlüter T. (2008) *Geological Atlas of Africa.* [4] Moreau et al. (1994) Tectonophysics, 234: 129-146. [5] Bowden P. et al. (1976) Nature, 248: 297-299. [6] Karche J. P. and Vachette M. (1978) Bull. Soc. Geol. Fr., 20: 941-953. [7] Delisle G. (2004) Environmental Geology 46, 1024–1029. [8] Schmieder M. et al. (2013) Journal of Asian Earth Sciences, 64: 58–76. [9] Earth Impact Database (2011). [10] Reimold W. U. and Koeberl C. (2014) Journal of African Earth Sciences, 93: 57-175.