Survey of Remote Sensing Techniques Used for the Anomaly Detection at the Presumed "Pyramid" Locality near Visoko, Bosnia and Herzegovina

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NOTE:

This report was generated *pro-bono* on a request made by the scientific advisory board of the *Bosnian Pyramid of the Sun – The Archaeological Park Foundation*. This is an independent remote-sensing site assessment report, without a-priori knowledge of the site, its findings are preliminary and pending field verification by the subject-matter-expert personnel.

INTRODUCTION:

Even though the availability of usable imagery over Bosnia and Herzegovina is sparse (chiefly because of often cloudy/foggy conditions during acquisition), several promising datasets, acquired in the window between 2001 and 2005, have been located and granted for preliminary studies (open source, granted permission or personal archives of Dr. Smailbegovic/procurement through personal funds). These images have been georectified and registered to a stable topographic base (orthorectified to 1:50,000 scale), derived from the existing maps for the area (digitized NITF at 1:50,000 and digitized 1:24,000 maps from Geodesic Institute of BH) and 1 Arc-Second resolution topographic mesh from the Shuttle Radar Topography Mission (SRTM) and 1:2,500 DTM from aerial stereo-photo pairs . Registration of imagery was absolutely necessary in order to detect/compare any possible correlations in the imagery and allow for horizontal integration of disparate geospatial datasets.

LINKS TO SOME OF THE SENSING SYSTEMS USED:

ASTER/ALI – Multispectral, EOIR satellite system.
IKONOS/OrbView – Commercial, high resolution satellite systems.
HYPERION – Hyperspectral satellite system
RADARSAT – Radar satellite system.
LANDSAT ETM – Multispectral satellite system.
SRTM – NASA Shuttle radar topography mission.
SPOT – French imaging satellite constellation.

BACKGROUND:

Geo-archaeological applications of remote sensing imagery are becoming more accepted in the recent years, with the wider application of high resolution spaceborne imagery-on-demand. The researchers note that the applicability of remotely sensed datasets is enhanced through horizontal integration with other geospatial and geospatial datasets, however **it must be emphasized that remote sensing, though extremely useful in some cases, is not a silver bullet – ONLY A CUEING TOOL**. The famous example of the "Lost City of Ubar" being found with remote sensing site was actually a combination of historical research, remote sensing data and a lot of hard work in both arenas.

DATA and ANALYSIS:

The high resolution panchromatic (1.0m resolution) and color imagery (2.27 m resolution) obtained from OrbView satellite and aerial photography (courtesy: Geodesic Institute of Bosnia and Herzegovina) have been color balanced and a composite derived by registering color image to panchromatic image and then corrected for Intensity, Hue and Saturation (IHS) balances resulting in a stable, high resolution imagery for detailed geomorphologic or texture mapping. The imagery was overlain on a digital topographic model (DTM) and viewed from different angles, using different false illumination parameters (illuminating the target form the areas it is not normally illuminated). The same procedure was repeated on the a) blank topographic model (generating shaded topography with slope and aspect angles) and b) integrated photo-topo set to note any anomalies (flat sides, geometric shapes, lineaments). Using the information from 1:50,000 scale topographic maps of the area (courtesy: Geoimage), obvious, current-use, man-made targets (e.g. urban areas, roads etc.) were subtracted from classification, leaving only a dozen targets showing inherent linear and/or geometric anomalies (**Figures 1 and 6**). Within the immediate target area, two primary and three secondary anomalies were noted. The primary anomalies (Visočica and Pljesevica mounds) exhibited flat, triangular sides, aligned in NSWE directions, flat tops and clear geometric "break-lines" between the flat sides. The automated linear-anomaly detector LINANAL (originally developed for tectonic studies of topographic lineaments) estimated the break angles of 43.822 degrees (+/- 1.6) on the exposed facets, repeated within the same error envelope on all exposed sides (**Figure 2**). The observed phenomena should not be confused with triangular facets normally occurring in a tectonic setting, for those occurrences only exhibit single-side triangulation and are uneven in the appearance with a far lesser or greater incidence angle, whereas the observed anomalies exhibit two or more, even triangular sides with 4, ~~ 40-48 degree angular breaks. Furthermore, no observed fault strikes correspond with the triangular occurrences on the mounds, thus eliminating the possibility that they were a secondary product of recent tectonic movements.

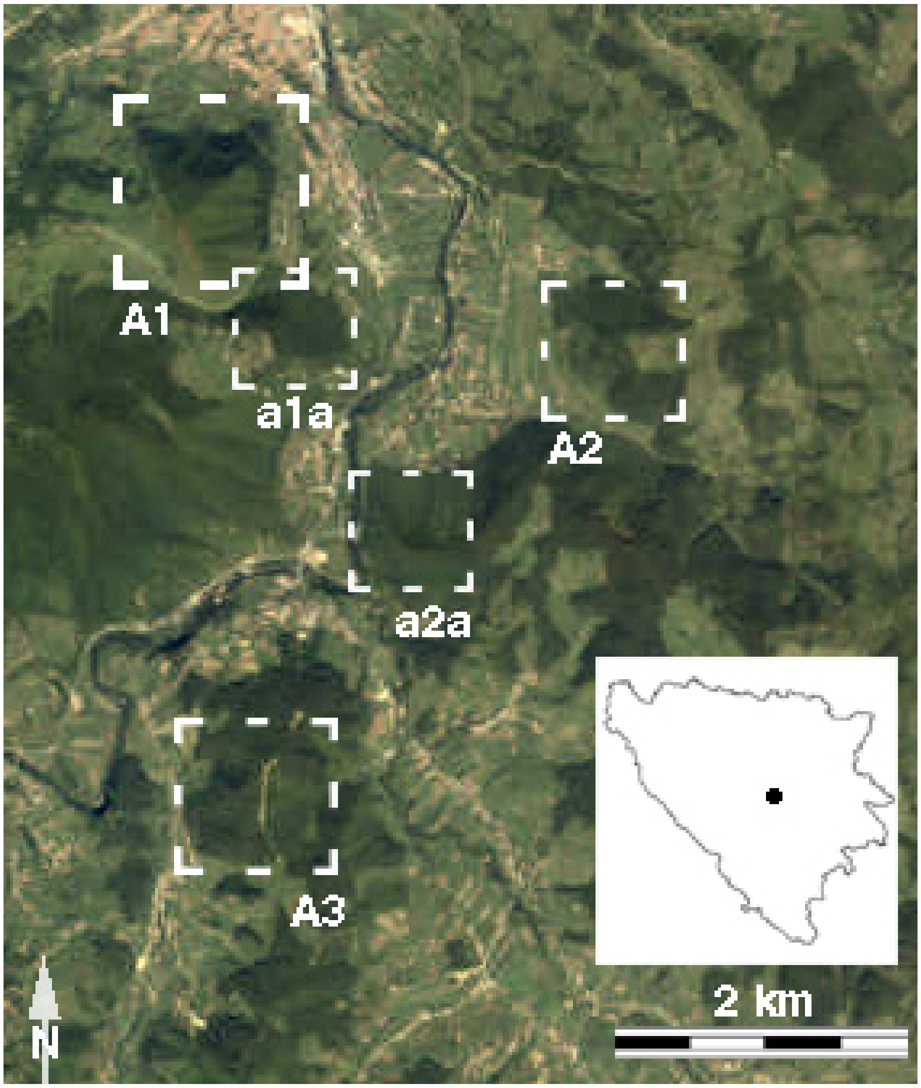

Figure 1 – Primary anomalies and location map (A1 – Visočica, A2 – Pljesevica, A3 – Dautovci (site)) and secondary anomalies (a1a – Unnamed, a2a – Krstac) noted on an 8m resolution regional color satellite image.

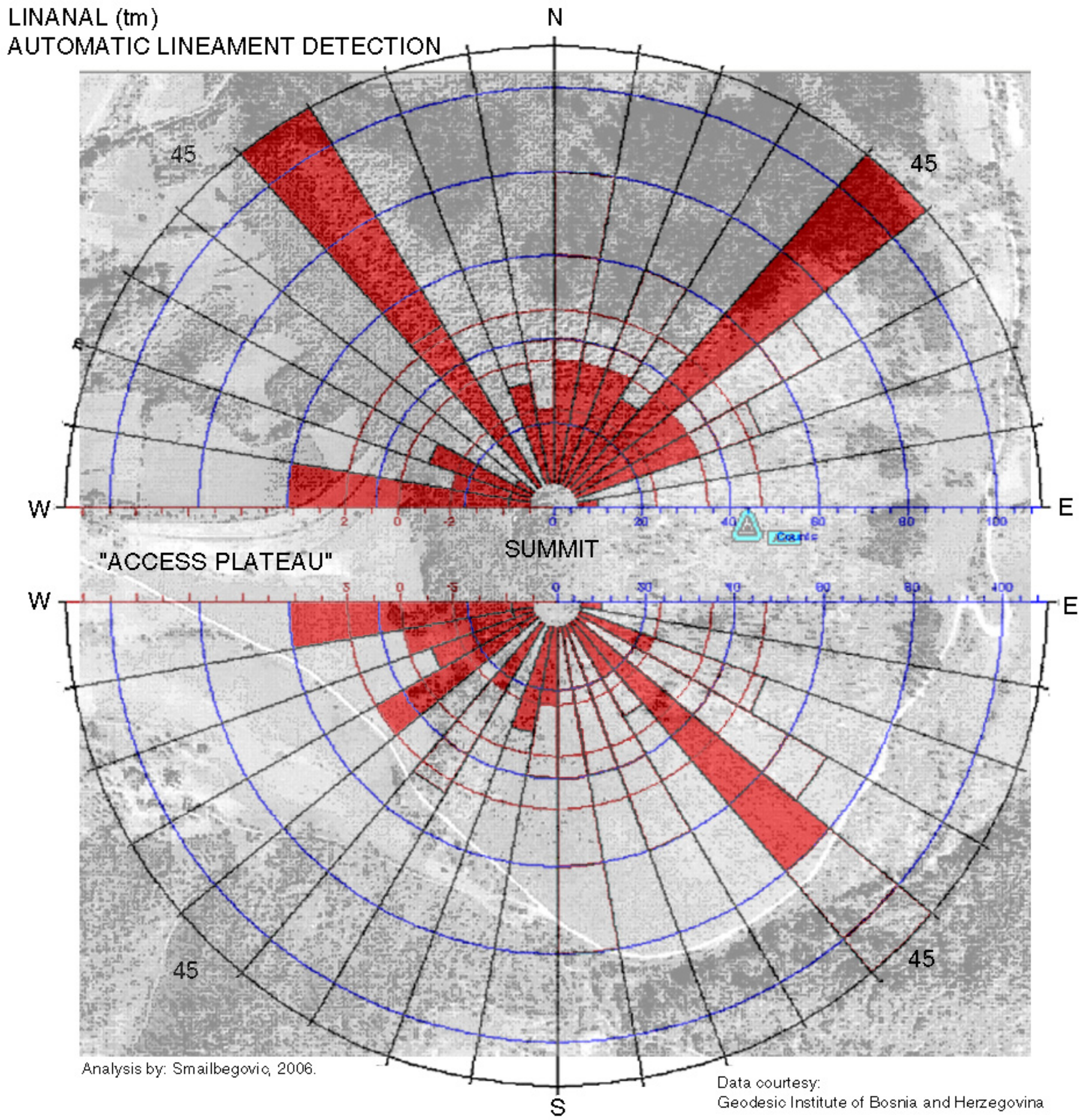

Figure 2 – Results from automated lineament detection on the available, high resolution datasets over Visočica mound (and image base for a quick reference). Note that the preferential orientation of the lineaments.

An additional geomorphic occurrence of interest was noted when the high-resolution satellite imagery was merged with the high-interval elevation contour datasets (**Figure 3**). An apparent terracing was clearly visible on the northern and to a lesser-extent, eastern exposures. The western exposure exhibits a leaning Y-shaped access plateau to the hill itself, terminating about two-thirds from the top. Only the southern side of the mound appears to have suffered erosion and is also the only one with the developed drainage features. The presumably preserved northern and eastern exposures do not exhibit significant evidence of surface drainage and only minor erosion. Wooded vegetative cover is only noted in the areas where it was artificially planted in the early 1970's by the Yugoslav National Army.

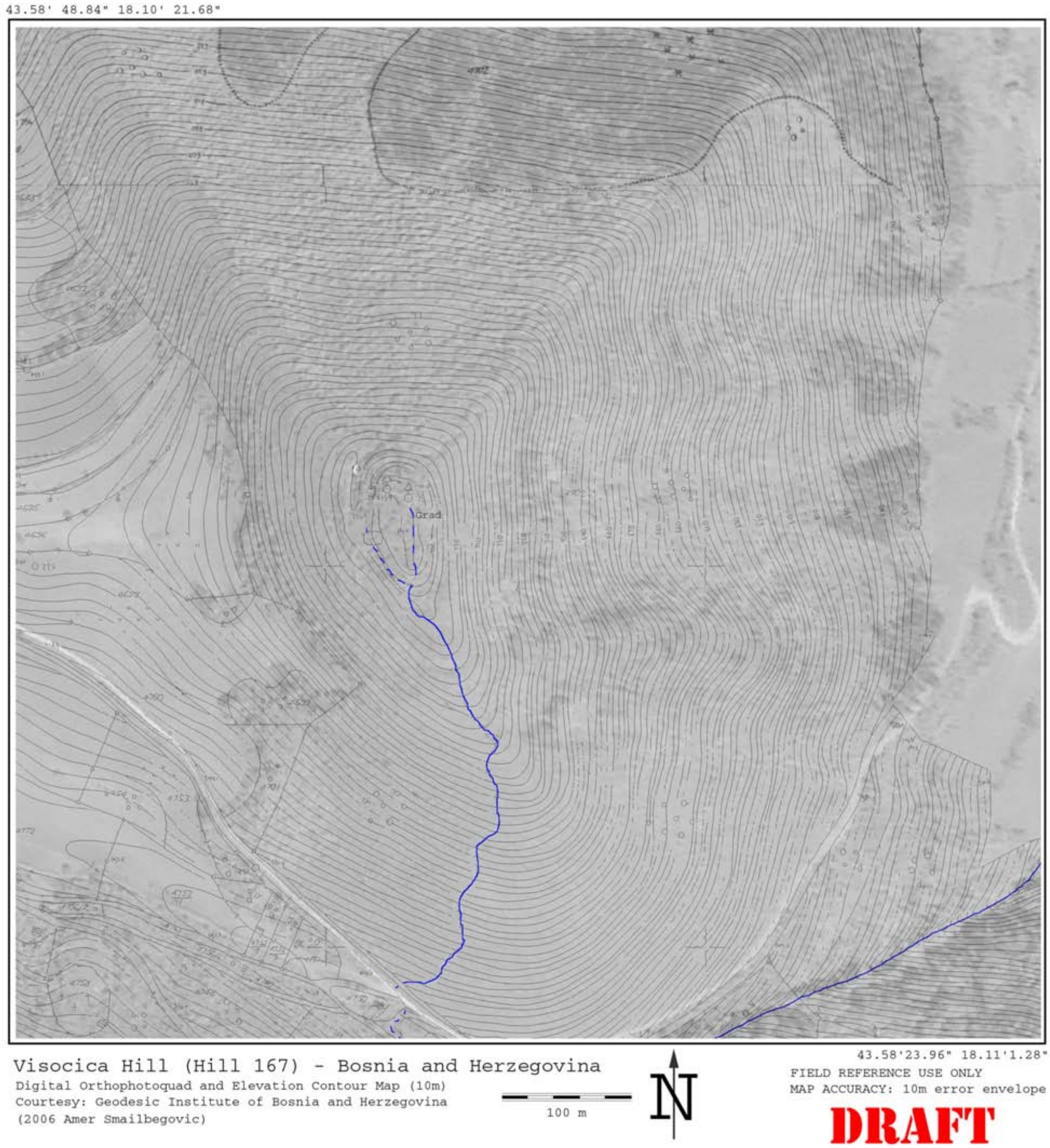

Figure 3 – Preliminary merged maps of Visočica (Anomaly: A1) showing high resolution satellite imagery (1m) and 10m elevation contour map. Data courtesy: Geodesic Institute of Bosnia and Herzegovina.

Additionally, some lower resolution satellite color (8.31 m resolution Advanced Land Imager (ALI) data), visible-shortwave-thermal (15m – 30m – 60m resolution Advanced Spacebrone Thermal Emissive Radiometer (ASTER)) and radar data (15m resolution RADARSAT data were acquired for the analysis. The existing Hyperion (30m) data were excluded from the analysis due to heavy atmospheric noise and inability to derive stable atmospherically-corrected reflectance over the target.

The ASTER images have been properly normalized for atmospheric effects using several atmospheric models. The visible-near infrared (VNIR) and short-wave infrared (SWIR) data were initially analyzed (**Figure 4**) using band-ratios and principal-component analysis to highlight the regional distribution of particular geologic materials (e.g. carbonates, clays, sulfates, silicates) where they are not obscured by dense vegetative cover. The results show that the area is dominated by clay materials in the valleys, some volcanoclastic and sedimentary facies in the hills, whereas some carbonates and areas of hydrothermal alteration also occur in the area. The target areas, where not covered with shade or dense vegetation mainly show surface soil (clay-based) characteristics. Therefore, short-wave infrared data contribute only moderate information about the overall surface geologic content of the area.

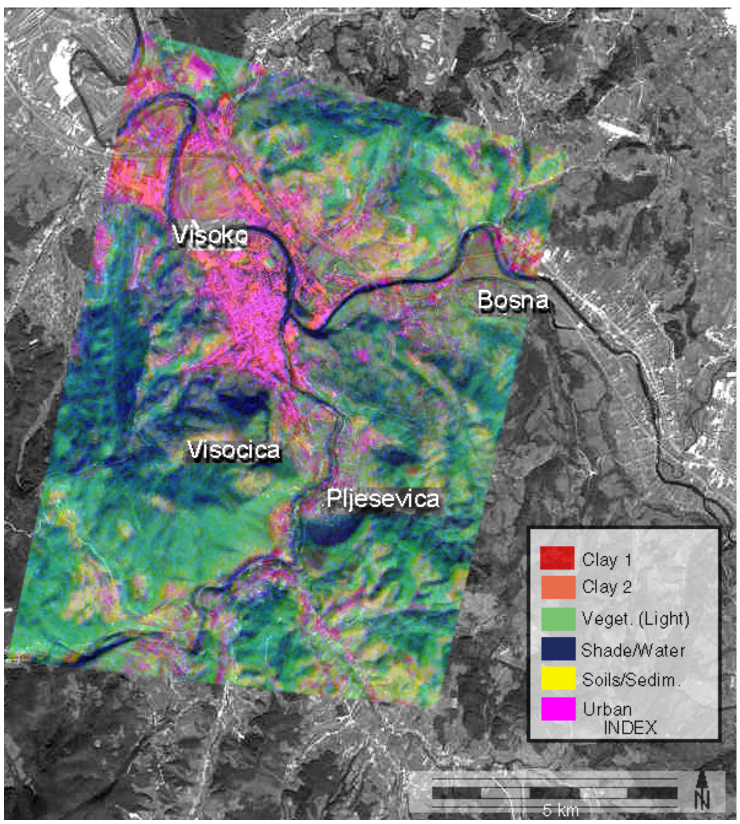

Figure 4 – Results of ASTER SWIR band analysis (30m) draped over 8m base imagery. The classes mainly show developed soils, vegetation and urban areas and offer only moderate level of terrain information.

The thermal region of ASTER yielded better results, but its lower resolution hampered detailed investigation (**Figure 5**). Two sets of ASTER scenes (same path and row) were collected for the area, day scene (1142 GMT (Zulu) pass) and a night scene (2137 GMT pass). Even though, the temporal gap for thermal inertia mapping was relatively large, for the given area these were the only available sets. Good overall anomaly definition was attained throughout the target using this technique, but limitations in estimating thermal inertia for area's rock types produced errors and made precise mapping of the mounds difficult. The second approach involved minimizing the effects of thermal inertia by averaging ASTER daytime and nighttime radiances. After subtracting the effects of topographic shading (through DTM), albedo and minimizing the effects of vegetative cover (from VNIR data) from this "averaged" image, it was possible to delineate the larger Visočica target (60m resolution data tends to be coarse), from the surrounding area. The results of the thermal inertia suggest that the target may be composed of less consolidated material and tends to "cool faster" than the surrounding mounds (presumed denser). The findings would be consistent with initial field observations (see Geologic report addendum to this text and/or Geologic Report by Nukic, 2005) or what would be expected from an artificial or artificially modified structure – lesser density materials, porosity, internal cavities all contribute to an increased heat loss.

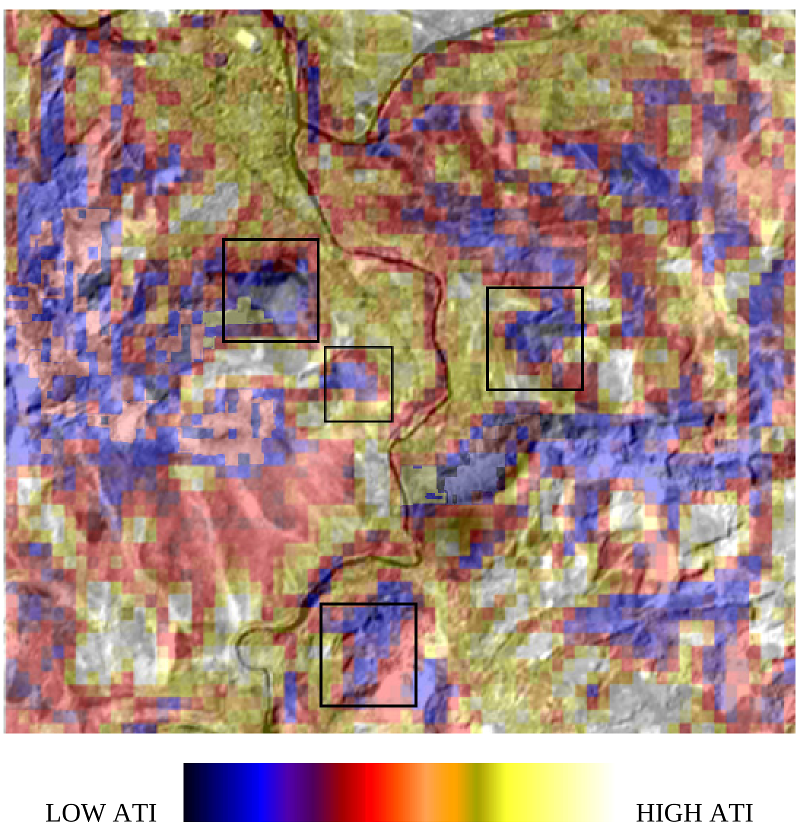

Figure 5 – Apparent thermal inertia (ATI) map derived from daytime and nighttime ASTER imagery. Anomalous isolated low ATI regions are delineated with squares. The image is a 60m resolution ASTER thermal composite registered and sharpened with a 15m composite ASTER panchromatic band.

OVERALL TRENDS:

Several other geospatial datasets are currently undergoing analysis and the results will be added on this report as they become available. However on the basis of the data analyzed thus far, it is possible to note the following trends:

- Several mounds exist in the Visoko valley area, which tend to have very geometric (triangular) sides and clear, linear breaks. These features remain visible and apparent even under different viewing/illumination angles.
- These mounds appear to be arranged in a triangular fashion, mutually equidistant and aligned in NSWE direction. All mounds are of approximately same height, but differ in the overall size.
- The lineaments noted near the break-lines of the hill appear to be aligned in roughly N45E, N45W and S45E directions. Minor S45W trend is noted as well as lineaments which may be associated with the “access plateau” noted on the west side.
- All mounds appear to have undergone some degree of erosion and are currently covered with moderate vegetative cover and somewhat developed soils. The south side of Visočica.
- Drainage and geomorphologic analysis of Visočica using high-resolution elevation contour charts and imagery suggests that the triangular faces do not exhibit significant development of drainage patterns, only the southern flank exhibits intermittent stream. It should be noted, that a large, 3km long E-W lineament is separating Visočica (on the south side) from the nearby hill (labeled “anomaly a1a”) – this feature may be of tectonic nature and should be investigated whether it had any effect to the present-day state of the southern flank.
- The largest mounds, Visočica and Pljesevica appear to irradiate heat faster (low apparent thermal inertia) than the surroundings, and the shape of ATI anomalous zone appears to be localized to the immediate area suggesting relatively unique composition or lower density of the structures. It cannot yet be determined what layers (if any) are responsible for the presence of this anomaly.
- Several possible faults exist in the area, but the overall, inferred strike of the faults does not correspond with the location of the mounds and the observed triangular sides (this excludes the possibility that the triangular sides of the mounds are triangular facets).

On the basis of limited geospatial information, it is compelling to state that the mounds represent highly anomalous features, which may be caused by some degree of anthropogenic activity in the. Due to overall lack of natural geomorphologic processes that would otherwise effect the observed features, the author recommends that the area should be ground-truthed for possible evidence of anthropogenic activities.

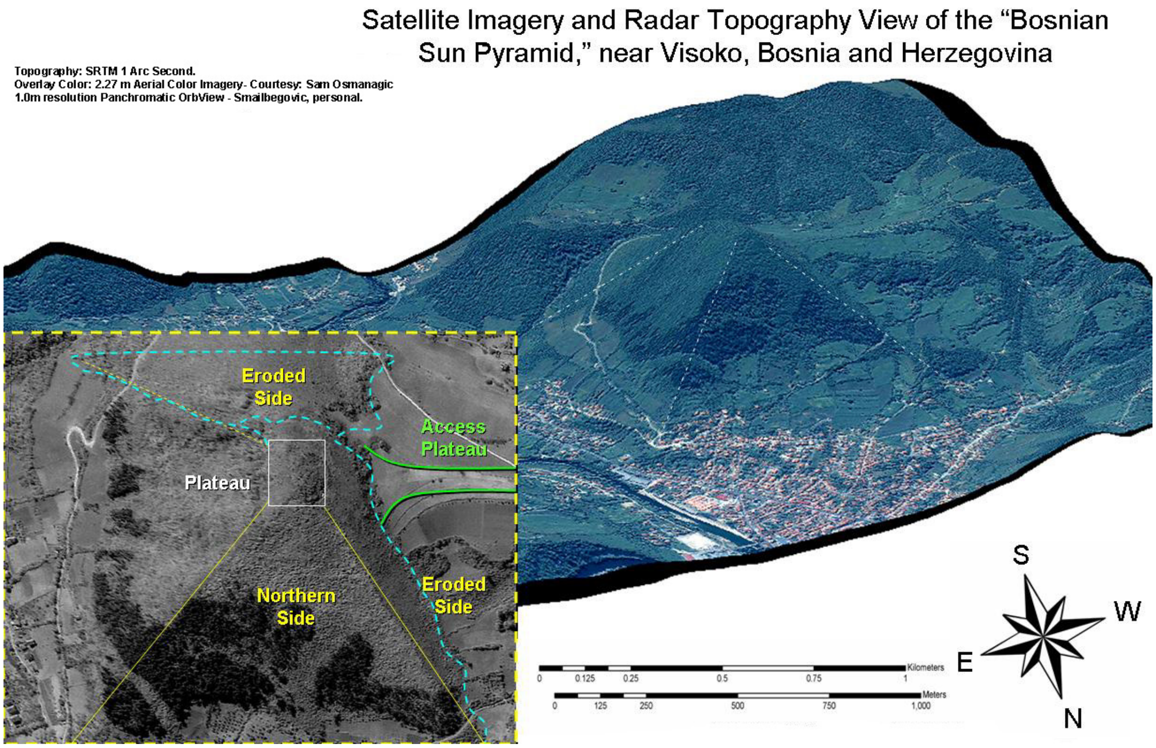

Figure 6 – High resolution airborne and spaceborne imagery over Visočica, with indexed anomalies. Topography: SRTM, overlays: orthorectified (1:50,000) airborne and spaceborne imagery (Courtesy: Geodesic Institute of Bosnia and Herzegovina).

Appendix 1 –Geologic site assessment by Nukic, 2005 (summary).

The largest thermal and textural anomaly, centered on Visočica mound has been ground-truthed by a team of Bosnian geologists led by Ms. Nadija Nukic. Preliminary results of surface field mapping suggested that the shape of Visočica is a symmetrical geometric form, whose four sides are identical (except the front side where there is an apparent access plateau) and chiefly composed of sedimentary materials. Given that the observed rock structure is classified as water-lain, fine-grained sediments, it would be unlikely that a natural structure would form in such a regular, geometric shape. Additionally, geomorphic characteristics of the mound suggest that after periods of climbing under the same angle one reaches a flat plateau, approximately 2.5 meters wide, then another steep area follows, followed by another plateau, with the pattern repeated all the way to the top of Visočica. The drainage from the structure is localized almost exclusively to the edges, unlike on a natural mound, where water tends to flow haphazardly down the easiest path. These findings are congruent with the spaceborne interpretations of textural features and geometric shapes noted on the mound.

The results of core drilling, test-well sinking and limited trenching have confirmed prior observations and also revealed that the surface of the mound is comprised of layered sandstone blocks, which appear to have been manually processed (i.e. mechanically cut out of blocks) and cut to fit the required dimensions. The binding agent found between the sandstone blocks suggest the presence of a “clastic breccia,” a multicolored conglomerate comprised out of gravel, sandstone and shale with a connective matrix or cement composed of sandy carbon particles of quartz, feldspar and flakes of mica. The flat sides of the blocks, the contact zone and the binding agent are clearly visible. Further detailed cleaning of the contact line between the two sandstone blocks revealed that the blocks were manually processed beneath and that the surface was flat and smooth, with binding agent applied afterwards to the surface. The order of the blocks itself supports the finding: they were ordered like bricks in a brick wall - the upper block was moved inwards in relation to the lower one (**Figure 7**).

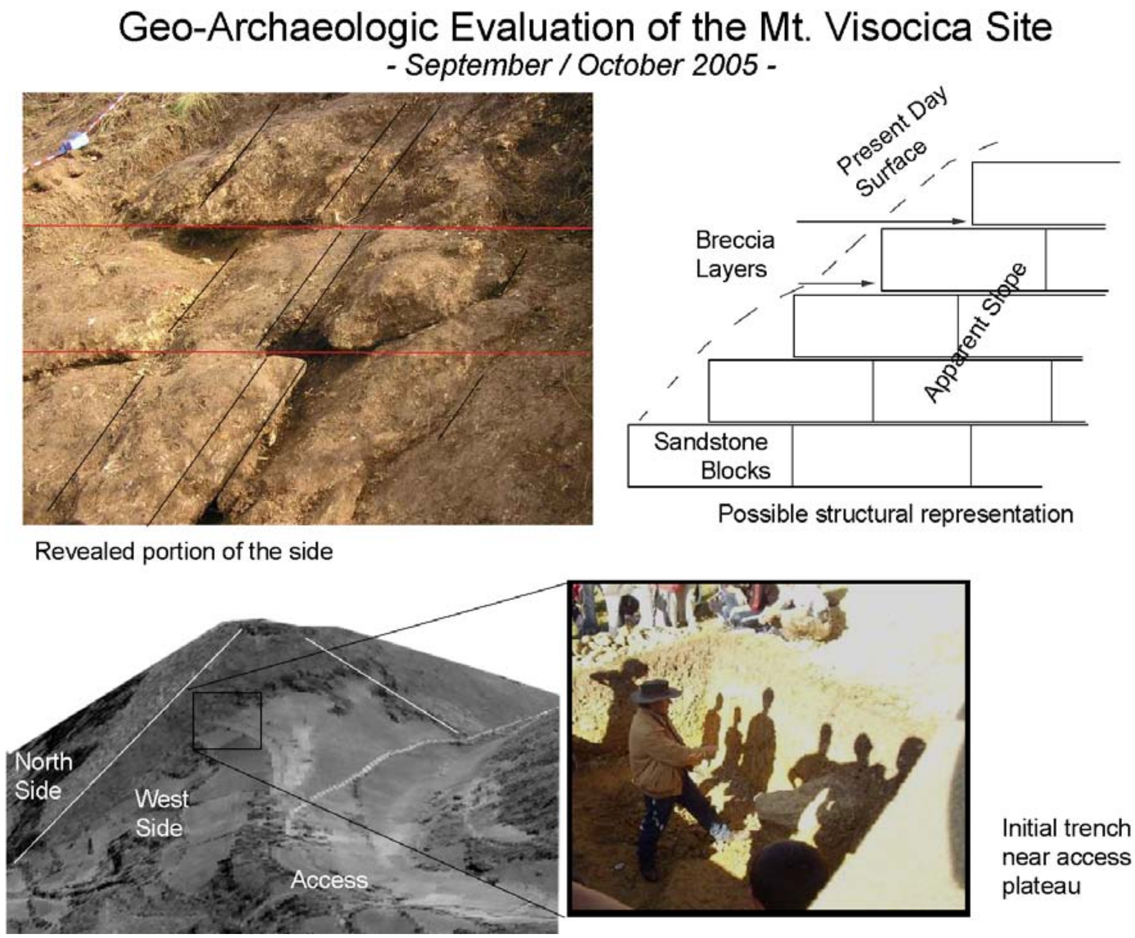

Figure 7 – Sample of geo-archaeological evaluations performed on site. Note apparent wall-like structure present on the exposed portion of the hillside.

Appendix 2 – Apparent Thermal Inertia Calculation and Reference

<u>From:</u> Anne B. Kahle – Surface emittance, temperature and thermal inertia derived from TIMS data for Death Valley, California. Geophysics Vol.52, No. 7. July 1987, P.858-874.

In order to separate the spectral and temperature information contained in the Thermal Infrared data, a method developed by Kahle et al. (1980) is used. It is assumed that the emittance of the ground at every point is equal to 0.93 in the wavelength region of 11.3-11.6 μm.

Planck's Law:

$$L\lambda = \varepsilon\lambda\ W_B\ (\lambda, T) = \varepsilon\lambda\ C_1 / \lambda^5\ [\exp\{C_2 / \lambda T\} - 1]$$

where

$L\lambda$ = measured radiance,
W_B = black-body radiance,
λ = wavelength,
T = temperature,
C_1= first radiation constant,
C_2 = second radiation constant, and
$\varepsilon\lambda$ = emittance.

Apparent Thermal Inertia (after Price, 1977):

$$ATI \sim (1-A) / \Delta T$$

References:

Kahle, A. B., Madura, D. P., and Soha, J. M., 1980, Middle infrared multi-spectral aircraft scanner data: Analysis for geological applications. Appl. Optics, 19; 2279-2298.

Price, J. C., 1977, Thermal inertia mapping: A new view of the earth: J. Geophys. Res., 82, 2582-2590.