The Acquisition and Assembly of Large Scale, High Resolution Photorealistic Models of Geological Outcrops*

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Abstract

The potential of photorealistic outcrop models is their ability to bring into the lab and the classroom an accurate surface representation of the outcrops. The draping of high resolution photos (to 1 mm per pixel) onto the TIN (Triangulated Irregular Network) mesh of a LiDAR (Light Detection and Ranging) derived model provides an accurate, lifelike appearance of the outcrop in digital form. The geologist can make most of the physical measurements of the outcrop that he would make in the field using the entire outcrop for analysis, rather than being limited to areas that he can physically access in the field. In addition, advanced analyses such as down-plunge cross-section, facies classification, and bed thickness characterization are facilitated with the digital model. The digital models allow the geologist to rapidly revisit the outcrop in the office for further analysis, to annotate the results, and to insert links to other documentation. However, there have been two major barriers to the adoption of photorealistic outcrop models for the study of geology – the effort required to assemble a large model at high optical resolution and a means to easily interact with the model and extract data. Custom software and hardware have been developed to enable the acquisition, assembly, and analysis of large scale, high optical resolution geological model

Method

In order to create a photorealistic model, a TIN mesh of the outcrop is created from a point cloud representation of the outcrop. High speed terrestrial LiDAR is used to scan the outcrop creating a point cloud representation of the outcrop at the desired physical spacing for the measurement points, typically 1 to 6 cm. Photographs of the outcrop are captured in the field and are then draped onto the TIN model by associating the triangle vertices of the TIN mesh with their respective points in the photographs. This mapping is accomplished in a file format that is used by common graphical processors, such as those that drive PC games. Figure 1 shows the process steps from point cloud to draped model. There are two major challenges in this process - the creation of the consolidated TIN mesh if more than one scan position is used and the precise alignment (sub-centimeter) of the photographs to the TIN mesh.

If the outcrop is scanned from a single position and the camera is mounted on and aligned to the scanner, the model assembly and the mapping of the mesh vertices to the photograph are straightforward. However, if the outcrop surface has high rugosity it must be scanned from multiple directions in order to avoid shadowing of the features of the outcrop. In addition, mounting the camera on the scanner limits the focal length of the lens and thus the resolution of the model. Multiple scan positions require professional assembly of the TIN mesh using commercial software in order to achieve an accurate representation of the surface. Dismounting of the camera from the scanner removes the focal length constraint but then requires that the images be independently aligned to the outcrop model using at least four tiepoints between each photograph and the model. If the tiepoints are manually defined, this becomes a very time consuming and highly inaccurate endeavor.

A robotic camera system that combines a pan-tilt robot with a robotic total station has been developed to rapidly acquire photographs of the outcrop and the tiepoint measurements, which are used to align the photographs to the TIN mesh model (Figure 2). The robotic camera and the total station are driven from a common software suite – GeoConstructor. The operator first defines the area to be photographed by navigating the total station and "shooting" points on the outcrop along the boundary of the area to be captured. The number of tiepoints per photograph (four is the minimum) is defined and the percentage of overlap of the camera photos is set. The software then controls the robotic total station shooting the XYZ location of the tiepoints and capturing a photograph of the cross-hair location at the time the point is shot. Once the parameters are selected and the area defined, the acquisition of the tiepoints is an automated process. After tiepoint acquisition is complete, the total station is removed from the tripod and the camera and pan-tilt robot are mounted. The camera is roughly aligned to the control reflectors that were shot by the total station during the survey stage of the process. The software then computes the angle of rotation and elevation for each camera shot, drives the pan-tilt robot to the correct orientation, and triggers the camera.

After the point clouds and photographs are captured in the field, the next step is the construction of the undraped TIN mesh model and the assembly of the photographs and the TIN mesh into a draped photorealistic model of the outcrop. If only a single scan position is used to create the model, the mesh can be created by linking the cylindrical matrix of LiDAR points into triangles. However, if multiple scan positions are combined to create the model, professional software such as Polyworks by Innovmetric must be used to combine the surfaces that are created from the various scan positions.

The final step in the process is the mapping of the TIN mesh vertices to their respective points in the photographs. The orientation of each photograph to the model must be determined. If the camera was mounted on the scanner, the orientation parameters may be exportable from the scanner project. If the camera is decoupled from the scanner, then for each photograph a minimum of four XYZ tiepoints must be associated with their UV coordinates in the photographs. Historically, this has been a manual process. The photograph coordinates and their corresponding XYZ locations on the model are identified by viewing the photograph and the model and making the assignment by moving the cursor over the corresponding features. For geological outcrop models, this is a time consuming and frustrating task, which often ends in failure to make acceptable associations. The lack of sharp, high-resolution features in outcrop models, which are abundant in manmade structures, is the cause for failure to make acceptable manual tiepoint assignments. Making the XYZ measurements in the field with a total station and taking a through-the-lens photograph of the cross-hair location allows for precise association of the XYZ measurement with the photograph using an image matching approach to align the total station photograph with the camera photograph. This method has been implemented in custom software GeoConstructor and allows for the capture and tiepoint assignment of 30 to 40 photographs per hour in the field. Figure 3 shows the first step in aligning the total station images with the photograph. Figure 4 shows the precise alignment of the total-station cross hair to the camera that is achieved using an image matching method. Figure 5 shows the result of aligning two high-resolution (~1 mm/pixel) photographs to the TIN mesh model. The image on the left has been darkened to highlight the quality of alignment of the two photographs.

After the precise alignment of a photograph is obtained, the vertices in the TIN mesh are mapped to their respective points in the photographs using the collinearity equations that are at the heart of stereo-photogrammetry. GeoConstructor provides a structured database for the photograph orientations and the TIN mesh model. GeoConstructor proceeds with the mapping process using a number of quality enhancement techniques. The user can select the order in which the photographs are draped on the model selecting the best photographs to be draped first with others filling in occluded regions of the model. An optimum angle algorithm can be used to prioritize photographs that are more face-on to the triangle surface ahead of photographs that were taken at an oblique angle. This minimizes oblique angle smearing of the photograph on the model. An occlusion geometry test prevents the draping of photographs in places on the model that were not visible to the camera lens. In addition, masking of areas of the photographs can be implemented to eliminate extraneous images on the outcrop surface. Such images might be a tree, person, or vehicle. A masked area would then be draped by another photograph that does not contain the unwanted feature.

After the photorealistic model is fully assembled, it is transformed into truncated and full UTM (Universal Transverse Mercator) coordinates. The full representation of the model in UTM coordinates requires that the numbers be double precision. The model is constructed at millimeter scale and UTM Northing requires 10 digits to fully represent the coordinate at millimeter scale. UTM Easting requires nine digits. Unfortunately, most model viewers use single precision coordinates – seven significant digits. Thus, the full UTM coordinates are truncated by the viewer, grossly distorting the shape of the model. The only viewer that we have seen that can handle full UTM coordinates is the ESRI ArcGIS suite of software such as ArcScene and ArcGlobe. In order for the models to be loaded into other viewers a truncated form of the UTM coordinates is used. The truncated coordinate models are geo-oriented but not geo-referenced. All orientation and distance measurements that are made on the geo-oriented models are as accurate as those of the models in full UTM coordinates.

Examples

The robotic camera system was used to capture two large outcrops in Saudi Arabia. A smaller set of outcrops in South Texas were captured using the scanner mounted camera method. In addition, a number of outcrops in Oklahoma, Texas, and Arkansas have been constructed in this manner.

Figure 6 is an overview screen shot of a road cut outcrop in the SW suburbs of Riyadh. The outcrop is a limestone/dolomite section of the Jubaila Formation, middle Arab-D. The model is about 1.3 km along the roadway and 1.4 km along the valley that the road crosses. The wall height along the roadway is 8 m at the SW end, upper right, and 20 m as it enters the valley, lower center. The valley is about 60 m deep. The photographs were taken with a Nikon D3X (24.5 Mpx) with 105 mm and 300 mm lenses. The entire outcrop was captured with the 105 mm lens resulting in 4 mm/pixel resolution for the road cut walls. Eight selected sites along the road cut were captured with the 300 mm lens, which yielded an optical resolution of about 1.3 mm/pixel. A total of 862 photographs were draped using the 105 mm images and each of the eight focus sites was captured with 16 to 24 photographs, depending on wall height, in a mosaic pattern with the 300 mm lens.

Figure 7 is an overview screen shot of a set of outcrops at the Meda'in Saleh archeological site, NW, Saudi Arabia. The outcrop is the fluvial sandstone Quweira formation. The model spans about 700 m X 700 m and the central outcrop is 75 m high. The entire model was captured with 806 photographs using a 105 mm lens resulting in optical resolution of 3 to 4 mm/pixel. The lower portion of the central outcrop was captured with the 300 mm lens with optical resolution of about 1.3 mm / pixel.

The two examples of outcrops in Saudi Arabia were captured using the robotic camera system. The other effective method of capturing an outcrop uses a scanner-mounted camera. Figure 8 shows an overview and close-up of an Eagle Ford Shale road cut outcrop in southern Texas, near Del Rio. Thirteen such models were created using a Nikon D700 (12.5 Mpx) with an 85 mm lens mounted on a Riegl VZ-1000 scanner. The scanner was about 25 m from the outcrop during capture resulting in an optical resolution for the models of about 2.5 mm/pixel. The screenshots of Figures 8 were taken while viewing the model in the ArcGIS ArcScene viewer. The thin nature of the bedding is clearly seen in the model in the viewer and the orthogonal bed thicknesses can be easily measured.

The advantage of the scanner mounted camera method is the automatic saving of the image to model orientation parameters. These are exported directly from the scanner software and used to drape the photos onto the model. The disadvantages of the method are the constraints placed on the height of the model that can be captured versus the resolution of the images versus the number of scan positions that it takes to capture the model. Image resolution is a function of the size of the camera sensor pixel, the lens focal length and the distance from the outcrop. The vertical height that can be captured is determined by the width of the sensor in pixels, the size of the sensor pixel, and the distance to the outcrop. For this example, at 25 m the maximum height that could be captured would be about eight meters. If the wall height was 14 m, either two scan passes would be required or the resolution would have to be reduced to about five mm/pixel.

Conclusions

An efficient method to capture and assemble high optical resolution geological outcrop models has been demonstrated. The models can be used in the lab or classroom for precise study of the feature orientations present in the model and dimensional measurements. With the proper software, strike and dip measurements, bedding thickness measurements, down-plunge cross-sections and more can be quickly created in the office. After analysis, the models can be revisited for discussion and explanation without having to return to the field.

Acknowledgements

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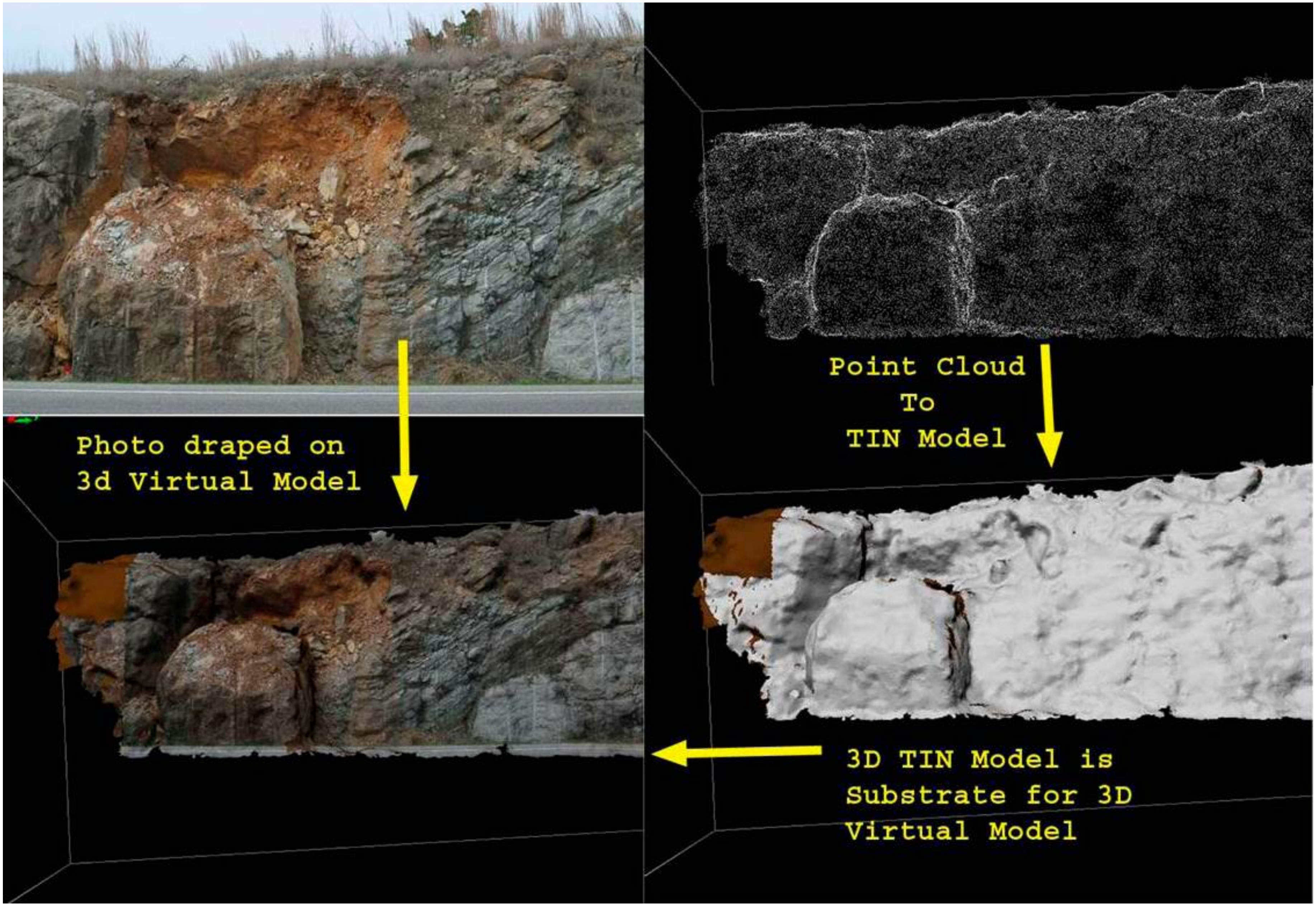

Figure 1. The point cloud is rendered as a TIN mesh. The mesh vertices are mapped to coordinates in the photograph creating a photo-draped 3D model. Royer Dolomite/Ft. Sill Limestone contact in the Arbuckle Hinge, along Interstate 35, southern Oklahoma.

Figure 2. Topcon IS robotic total station on the left. FLIR pan-tilt robot with Nikon D3X DSL camera and 300 mm lens on the right.

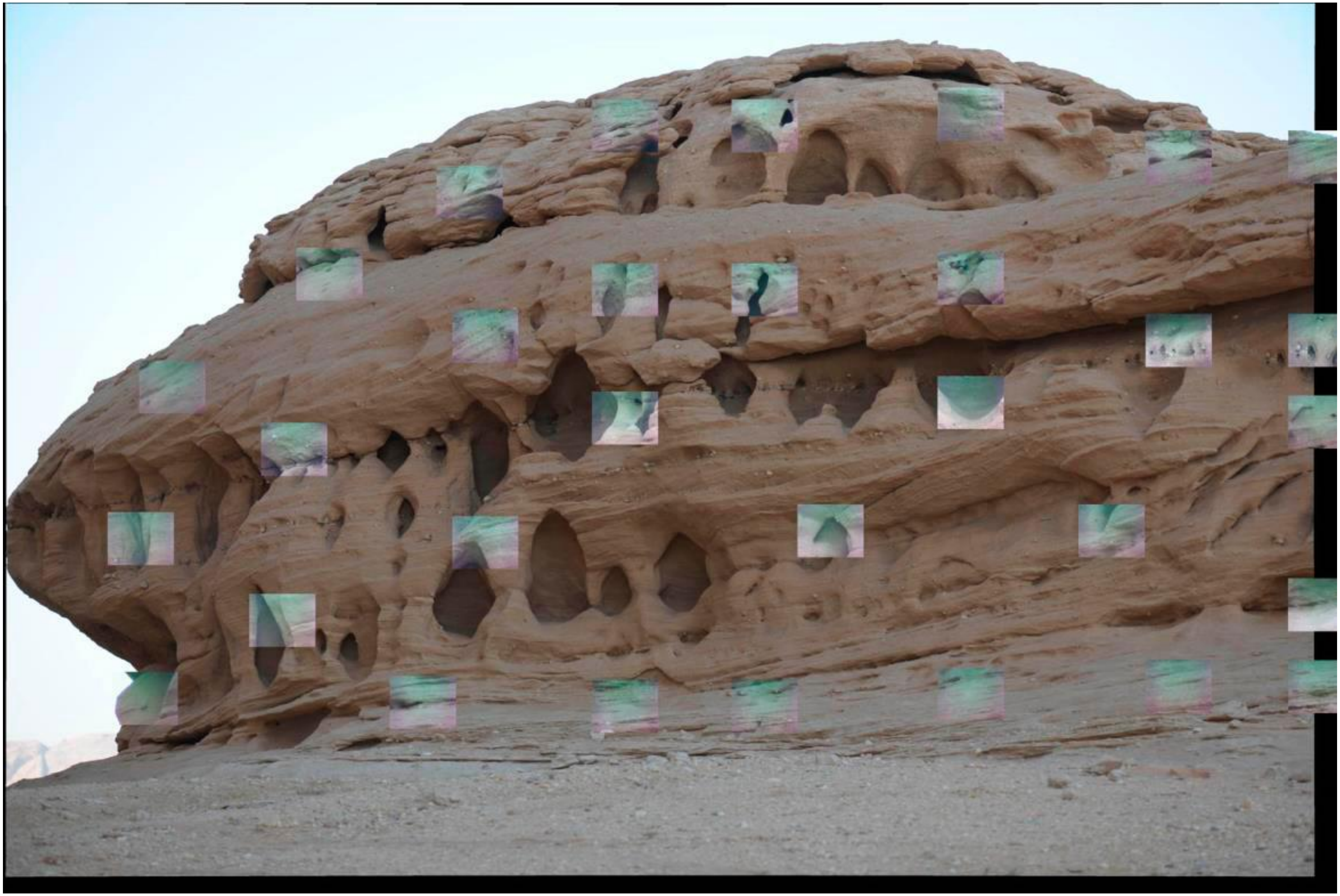

Figure 3. Camera photograph of outcrop with total station cross-hair images superimposed in their approximately correct location.

Figure 4. Alignment of the total station through-the-lens cross hair.

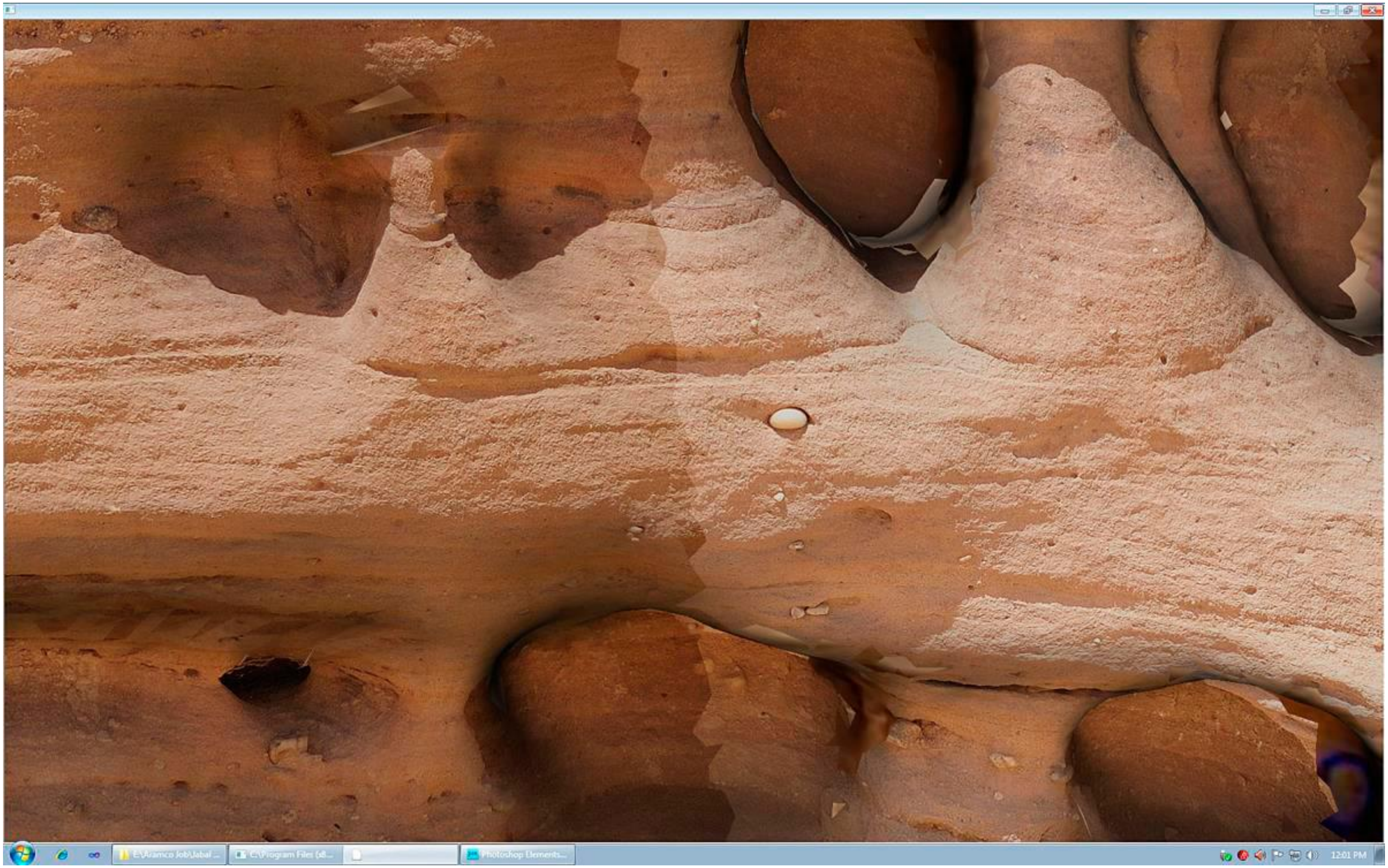

Figure 5. Precise alignment of high-resolution photographs using a robotic camera/total station system and image matching. Quweira Formation, Meda’in Saleh archeological site, NW Saudi Arabia.

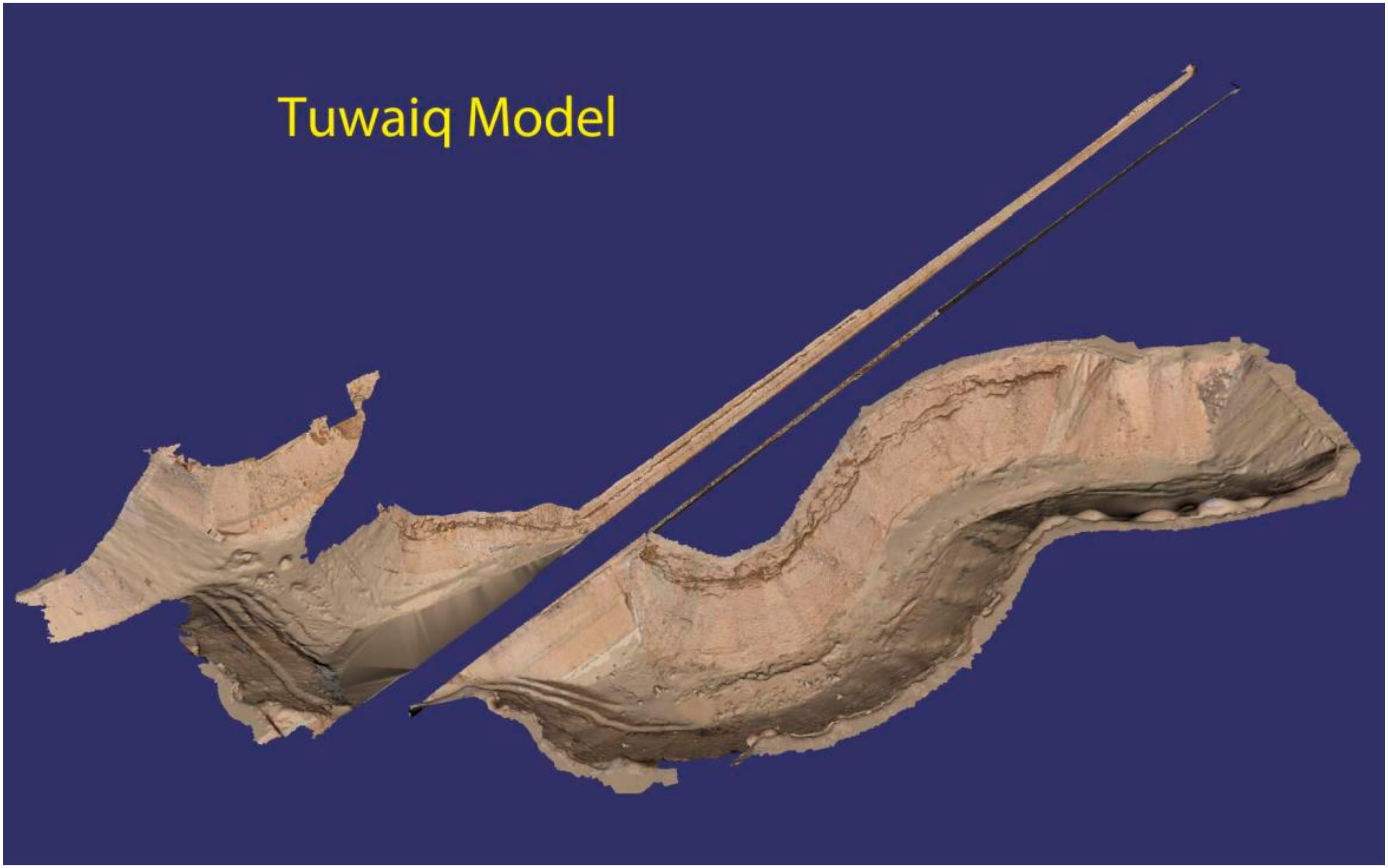

Figure 6. Road cut and valley outcrop model of the Jubaila Formation, Riyadh, Saudi Arabia.

Figure 7. Free standing outcrops of the Quweira formation, Meda'in Saleh archeological area, NW Saudi Arabia.

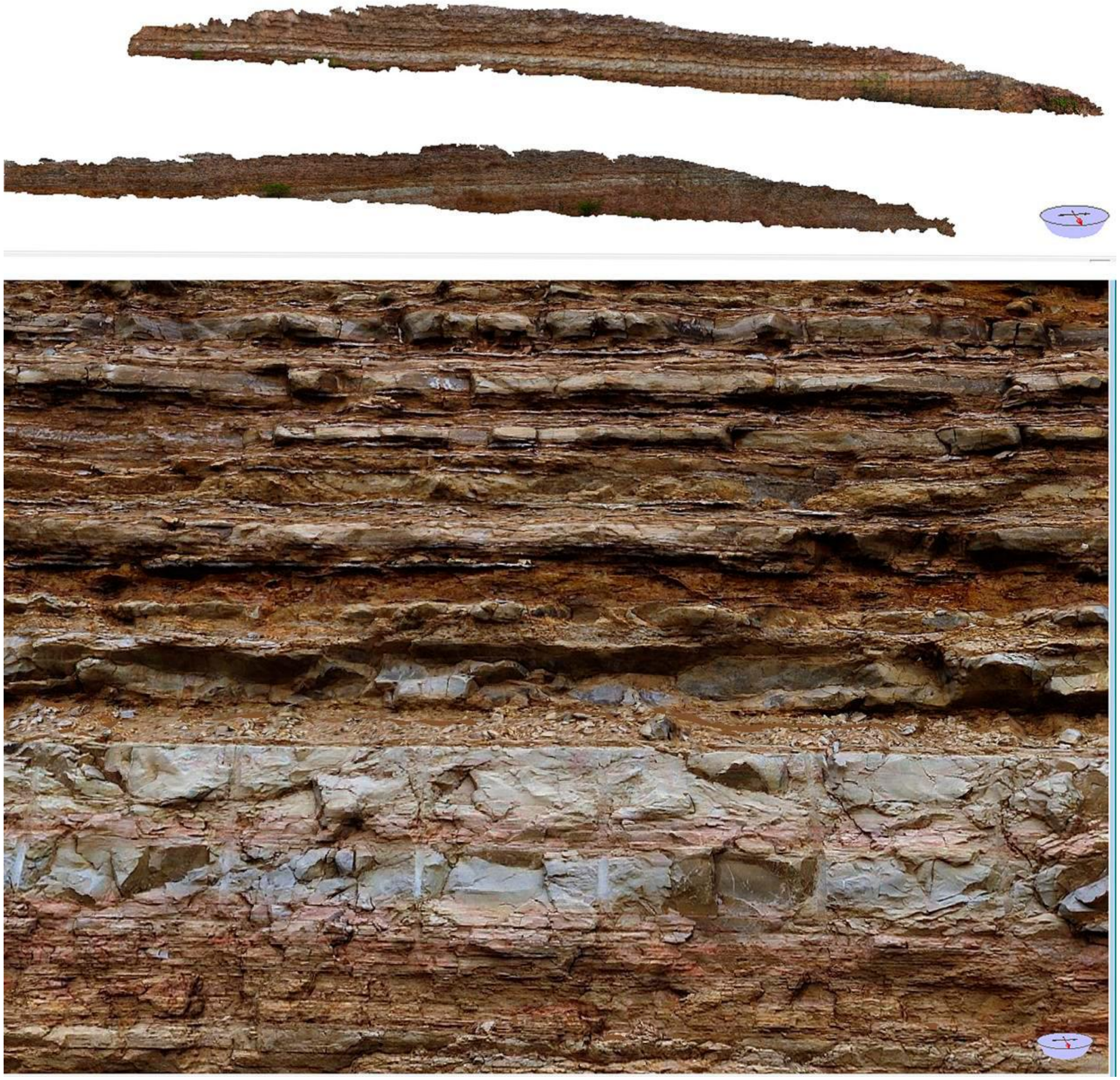

Figure 8. Overview and close-up screenshots of a 3D road cut outcrop model of the Eagle Ford Shale, near Del Rio, Texas, loaded into the ArcScene viewer.