Integration
geoConvention 2013
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The Analysis and Annotation of 3D Photorealistic Geological Outcrop Models

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Summary

Photorealistic models of geological outcrops provide a detailed replication of the outcrop in digital format. Loaded into a computer graphics system the model can be viewed, inspected, and measured with equal ease regardless of the height or accessibility of the outcrop in the field. Analytical capability has been implemented on the ESRI ArcGIS platform in the GeoAnalysisTools extension to ArcScene. Detailed orientation and thickness measurements can be made rapidly in the office. The tool set provides substantial documentation and annotation capability that is present in the ArcGIS software suite.

Introduction

Photorealistic geological outcrop models are a digital representation of the outcrop that combines photographs of the outcrop with either a point cloud representation of the outcrop surface or a TIN mesh surface of the outcrop. The level of detail that the model has is dependent upon the target resolutions (physical and optical) that were used by the field team at the time of data acquisition. In addition, the manner in which the data is rendered as a digital model affects the level of detail that the geologist can observe in the model. A colored point cloud representation of the model works fine for large scale features but fine details are lost when the geologist zooms-in to view the model close-up. In contrast, a photorealistic model that is constructed of photographs draped onto a triangle mesh surface that is derived from the LiDAR point clouds provides a level of detail that is limited only by the resolution of the photographs.

Photorealistic geological outcrop models provide the geologist access to the entire outcrop rather than just the lower 2 m. They can facilitate the measurement of orientation and distance such as strike-dip and bed thickness. Time consuming analysis such as down-plunge cross-section can be done in a matter of minutes on the outcrop model. Bedding can be delineated and facies classification can be added to the model. The model can be annotated, passed to others for review, and used as a training vehicle for other geologists.

After the geologist has acquired the outcrop model, he needs to extract data from it, otherwise it is just a “pretty picture”, interesting but not quantifiable. There are several different software products that provide varying degrees of capability. Some simply place points on the model using a model editor such as Polyworks by Innovmetric and then export the points for further analysis. More advanced techniques are employed in GoCAD, Petrel, and RockWorks. A software extension GeoAnalysisTools has been developed on the ESRI ArcGIS platform to analyze photorealistic outcrop models. The software has been applied to outcrops that contain complex structural deformation and to outcrops with distinctive sedimentary features.

Method

GeoAnalysisTools is an ESRI ArcGIS extension that imports photorealistic models into ArcScene and provides analytical tools to extract data from the model. The extension loads a photorealistic model as an ESRI multipatch file. The model file and all of the results of analysis are standard ArcGIS compatible files. Thus, after analysis, the user does not need to have GeoAnalysisTools installed to view and interrogate the results. The model and analytical results can also be loaded into ArcGlobe providing a large scale environment for viewing the results across hundreds of kilometers. The tool set includes applications that are directed toward structural and sedimentary analysis of the outcrop model. Standard measurements such as strike-dip and trend-plunge can be made. Down plunge cross-sections can be rapidly created by delineating the desired features on the model and providing a projection direction for the cross-section, such as the trend and plunge of a fold. Sedimentary facies can be delineated on the model and the section of the model that is outlined can be extracted as a stand alone polygon shapefile that is offset a short distance (e.g. 5 mm) in front of the model surface. By changing the display characteristics of the polygon shapefile, the underlying area that was outlined can appear to be tinted, thus classified. There is also a Jacob's staff tool that provides rapid measurement of bed thicknesses. Ancillary figures such as a radiometric chart or grain-size chart can be superimposed on the model and distorted (compressed or elongated) to align with the associated features in the model. All results of analysis are saved as shapefiles with critical measurements held in the ArcGIS attribute table of the shapefiles.

Figure 1 is an example of the analysis that was done in the ArcScene environment. The model is from the hinge zone of the Arbuckle Anticline along Interstate 35 in southern Oklahoma, Royer Dolomite and Ft. Sill Limestone contact. First, strike-dip measurements were made on the anticline-syncline fold on the right of the model as shown in Figure 2. The measurements use a technique similar to the "3-point problem" method. The geologist places a trace of points along the bedding while ensuring that there is dimensional relief in the placement of the points. A plane is then fit to the points resulting in the strike-dip measurement. The "intersection of strike-dip planes" option for trend-plunge was selected to determine the trend and plunge of the folding. The results of the strike-dip and trend-plunge measurements are automatically saved in the shapefiles for each of the measurement types. For strike-dip the software can insert rectangles into the model that represent the orientation of the bedding. For trend-plunge, polylines can be inserted indentifying the direction. In Figure 2 the attribute table for the strike-dip shapefiles is open showing the results of the analysis. Three measurements are shown selected and their corresponding rectangles in the model are highlighted.

In order to produce the bedding plane traces, first the bedding was delineated by placing points using the ArcScene graphics marker on the bed contact surfaces. The traces were then extruded in the trend-plunge direction yielding the folded surfaces that are shown in the bottom part of Figure 1. On the left side of the model is a decollement with the slip surfaces colored magenta. The decollement was traced by placing points along the slip surface and then extruding the trace in the trend-plunge direction. The axial planes of the folding are colored red. They were defined by tracing the points of maximum curvature in the bedding and then extruding the traces in the trend-plunge direction of the folding. To the upper left of Figure 1 fracturing and faulting can be seen that is a result of the stresses induced in the overlying layers by the decollement.

A byproduct of the trace extrusion is the automatic creation of a down-plunge cross-section, if desired. By selecting the 2D projection option in the software control screen, the extrusions are projected onto a plane that is orthogonal to the extrusion direction. The projected features are exported as 2D polyline shapefiles. Figure 3 shows an ArcMap exported image of the down-plunge cross-section. The cross-section was exported from ArcScene as a 2D polyline shapefile. It was loaded into ArcMap and the gridding of the cross-section and labeling was produced with the standard ArcMap tools. The shortening across one of the bed traces is determined by using the polyline length of the trace that is automatically available with the shapefile and the linear measuring tool (shown in the figure) which measures the straight line distance between the ends of the bed trace.

There are options available in GeoAnalysisTools to highlight defined areas in the outcrop model such as would be used for facies classification. The bedding that outlines the area is delineated. A seed point is placed between the bed traces that are to be classified and the software then makes a duplicate of the outlined area, moves it slightly in front of the surface of the model and then turns it into a polygon shapefile. By moving the polygon shapefile in front of the model, it can be used to tint the area behind it. This is shown in Figure 4, lower image. Each outlined bed is given a unique identifier in the polygon shapefile attribute table. By adjusting the transparency of the polygon shapefile and using the classified symbology option in the properties box for the shapefile for display, the outcrop area behind the polygon shapefile appears to be tinted.

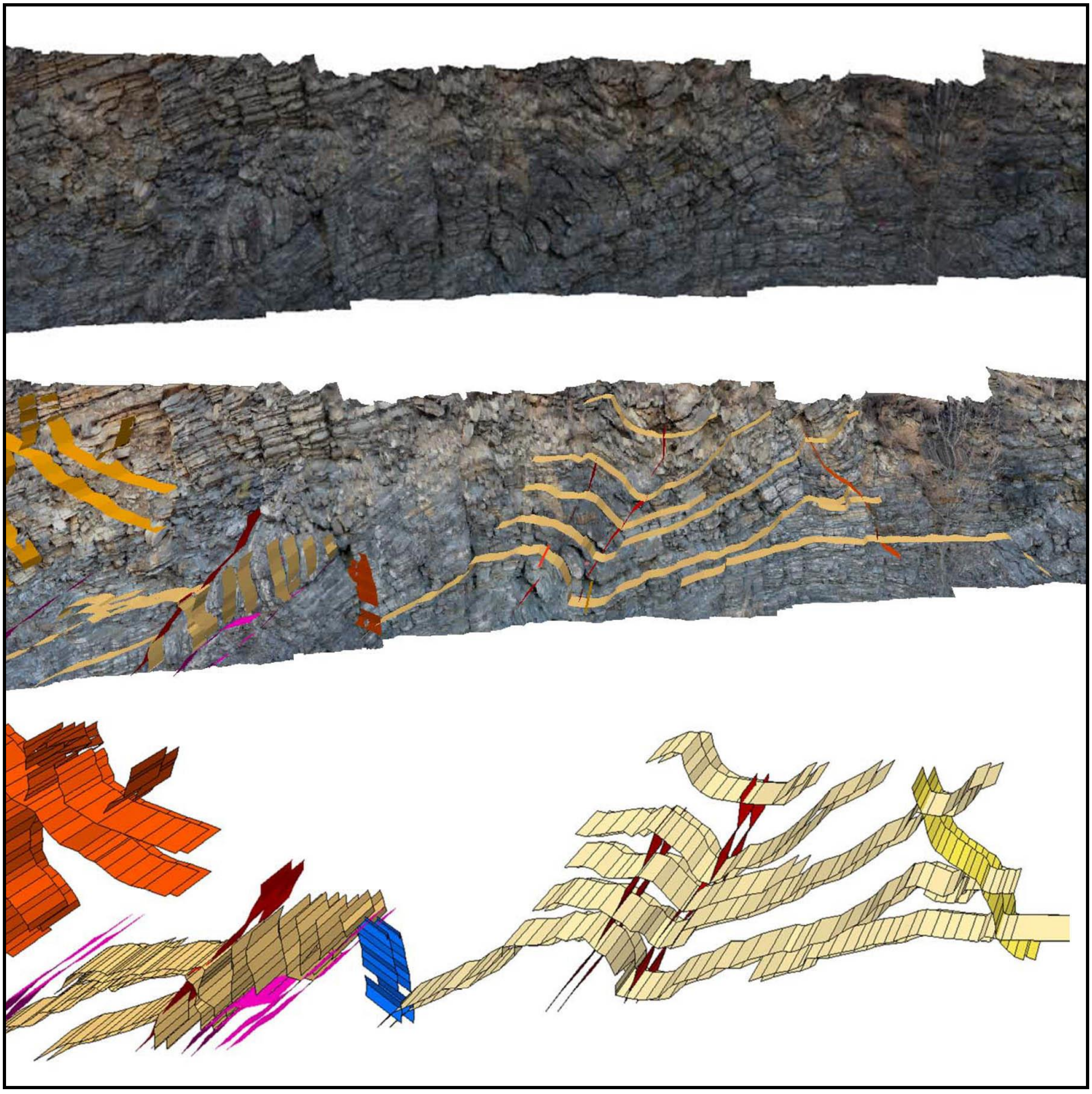
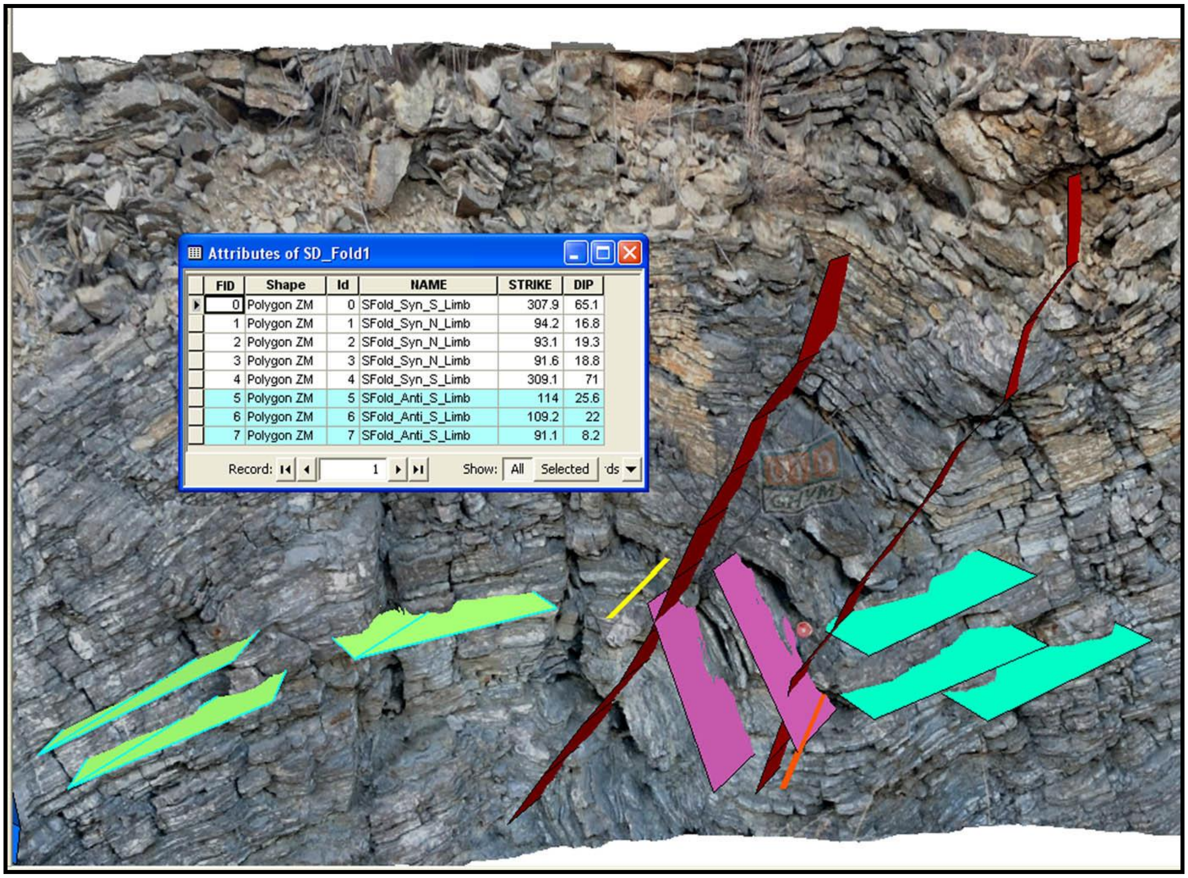


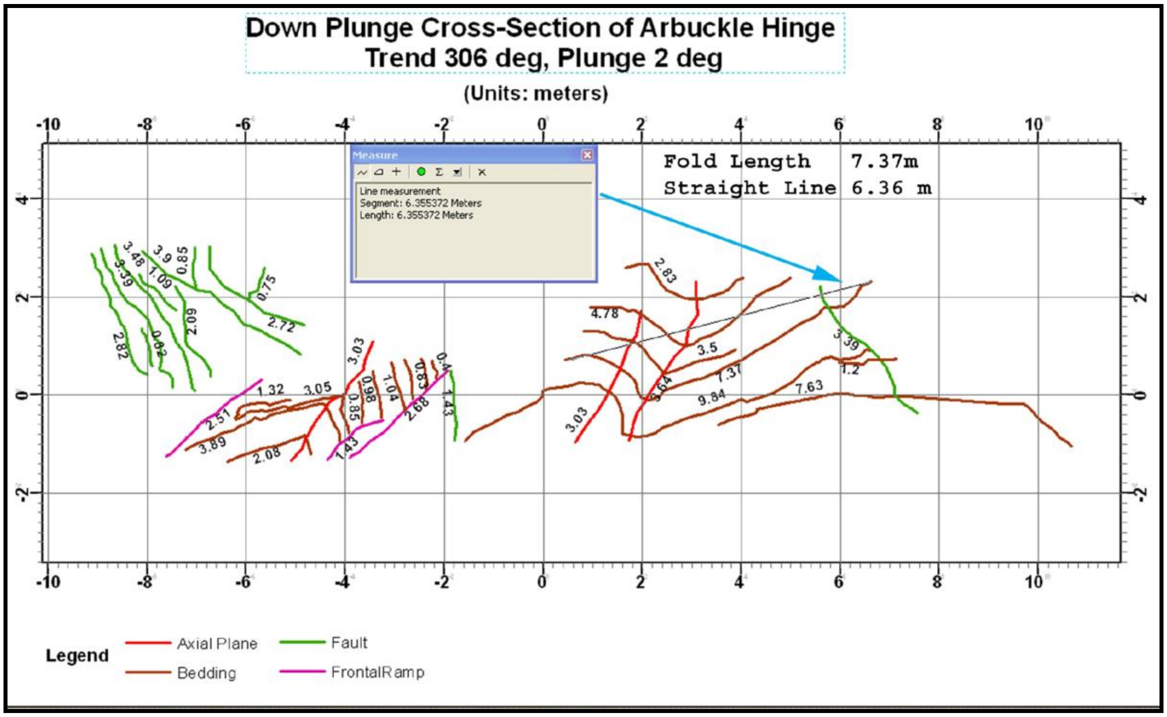
Figure 1. Hinge zone of the Arbuckle Anticline, Interstate 35, southern Oklahoma. The top figure is the model as seen in ArcScene. In the middle image, the bedding, slip surfaces, and axial planes were delineated using the GeoAnalysisTools extension to ArcScene. The lower image highlights the distortion and faulting that exists in the outcrop. The visibility of the model was turned off focusing the geologist on the results of the analysis.



Attributes of SD_Fold1

FID	Shape	Id	NAME	STRIKE	DIP
0	Polygon ZM	0	SFold_Syn_S_Limb	307.9	65.1
1	Polygon ZM	1	SFold_Syn_N_Limb	94.2	16.8
2	Polygon ZM	2	SFold_Syn_N_Limb	93.1	19.3
3	Polygon ZM	3	SFold_Syn_N_Limb	91.6	18.8
4	Polygon ZM	4	SFold_Syn_S_Limb	309.1	71
5	Polygon ZM	5	SFold_Anti_S_Limb	114	25.6
6	Polygon ZM	6	SFold_Anti_S_Limb	109.2	22
7	Polygon ZM	7	SFold_Anti_S_Limb	91.1	8.2

Figure 2. Strike-Dip and Trend-Plunge measurements of the anticline-syncline fold in the hinge zone of the Arbuckle Anticline.



Down Plunge Cross-Section of Arbuckle Hinge
Trend 306 deg, Plunge 2 deg

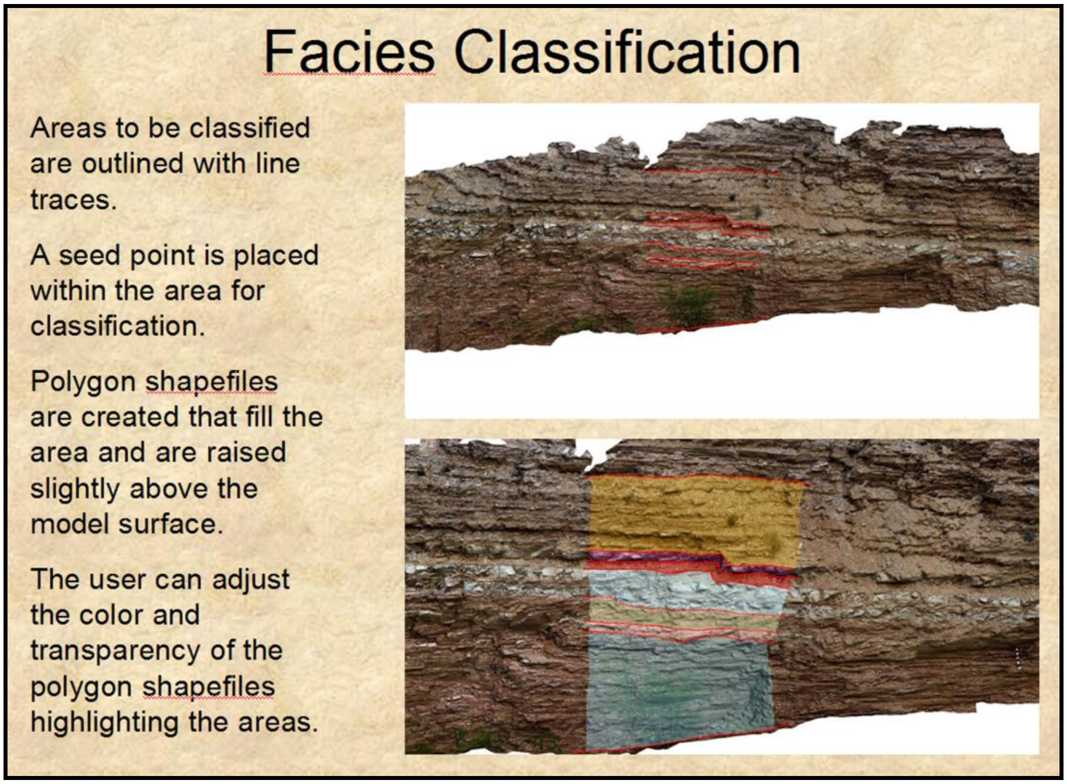
(Units: meters)

Measure

Line measurement
Segment: 6.355372 Meters
Length: 6.355372 Meters

Fold Length 7.37m
Straight Line 6.36 m

Figure 3. Down-plunge cross-section of extruded traces rendered and labeled in ArcMap.



Facies Classification

Areas to be classified are outlined with line traces.

A seed point is placed within the area for classification.

Polygon shapefiles are created that fill the area and are raised slightly above the model surface.

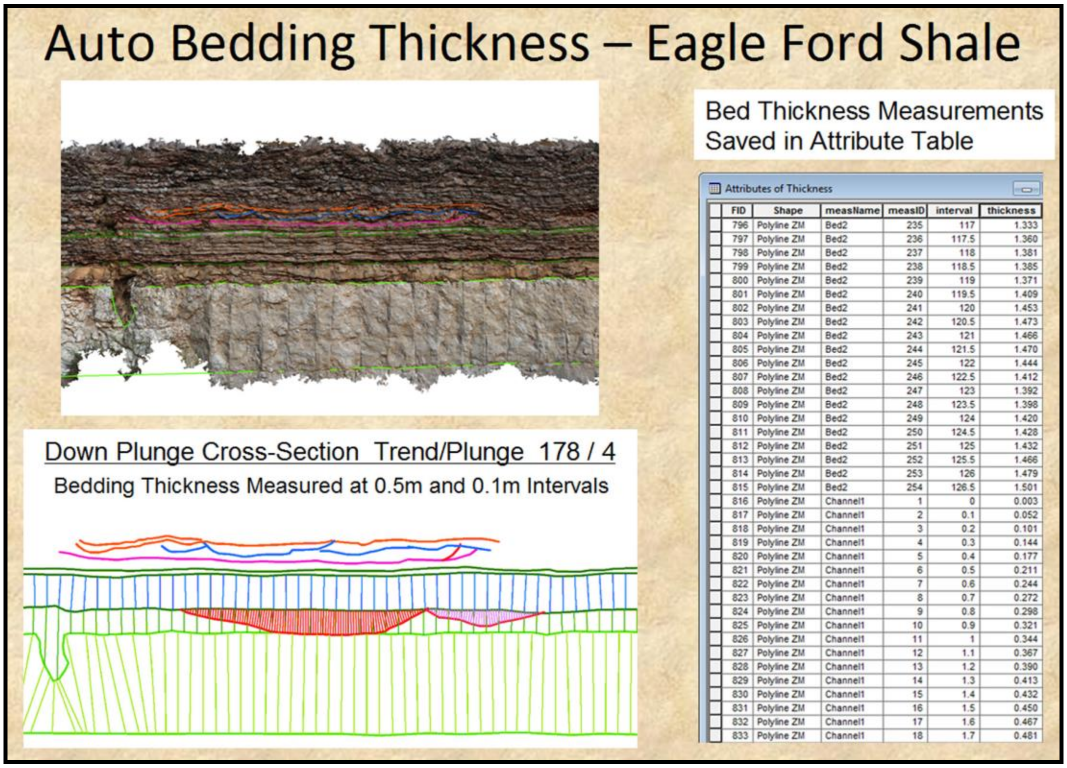
The user can adjust the color and transparency of the polygon shapefiles highlighting the areas.

Figure 4. Facies classification of an Eagle Ford Shale road cut outcrop in south Texas.

The GeoAnalysisTools extension for ArcMap provides for the automated measurement of bed thickness while stepping along the bed traces. The user delineates the bedding in ArcScene as shown in the top left of Figure 5. A down-plunge cross-section of the traces is created and loaded into ArcMap. The user selects two traces in ArcMap, defines a stepping distance, and activates the automated bed thickness tool. The result is shown in the lower left portion of Figure 5. On the right side of Figure 5 the attribute table for the auto-thickness shapefile is opened. All of the measurements that were made are loaded into the attribute table. If the geologist wants to determine the thickness of a particular bed, he can select the thickness line segment he wants to measure and the entry in the attribute table will be highlighted.

A means to rapidly measure the orthogonal bed thicknesses of the outcrop is available with the Rapid Jacob's Staff tool. The geologist places graphics points on the bed surfaces that are to be measured, provides the strike-dip of the bedding and activates the Jacob's Staff tool. The software will create the segmented measurement polyline shapefile shown in green in the lower left of Figure 6. In the upper left of Figure 6 is a red polyline that is a vertical guide for selecting the points. Guides can be created as vertical lines, horizontal lines, or as skewed lines between two selected points. On the right side of Figure 6 the attribute table for the measurement shapefile is opened. By selecting either a segment on the polyline shapefile or by selecting an entry in the attribute table, the geologist can identify which measurement belongs to which bed. Lines are automatically created from the segmented polyline to the picked point on the surface to further identify the bedding that is measured.

An image insertion tool is available to place an image that is aligned to the bedding just in front of the surface of the model. Figure 7 shows the insertion of a radiometric chart in front of the model and aligned to the bedding. During the insertion process the geologist is afforded the opportunity to provide link lines between the model and the associated points on the chart. The image is then locally compressed or elongated between the link points to achieve alignment of the image to the corresponding points in the model. The image is a polygon shapefile and by adjusting the transparency option in the display properties of the shapefile, the underlying features of the outcrop can be seen.



Auto Bedding Thickness – Eagle Ford Shale

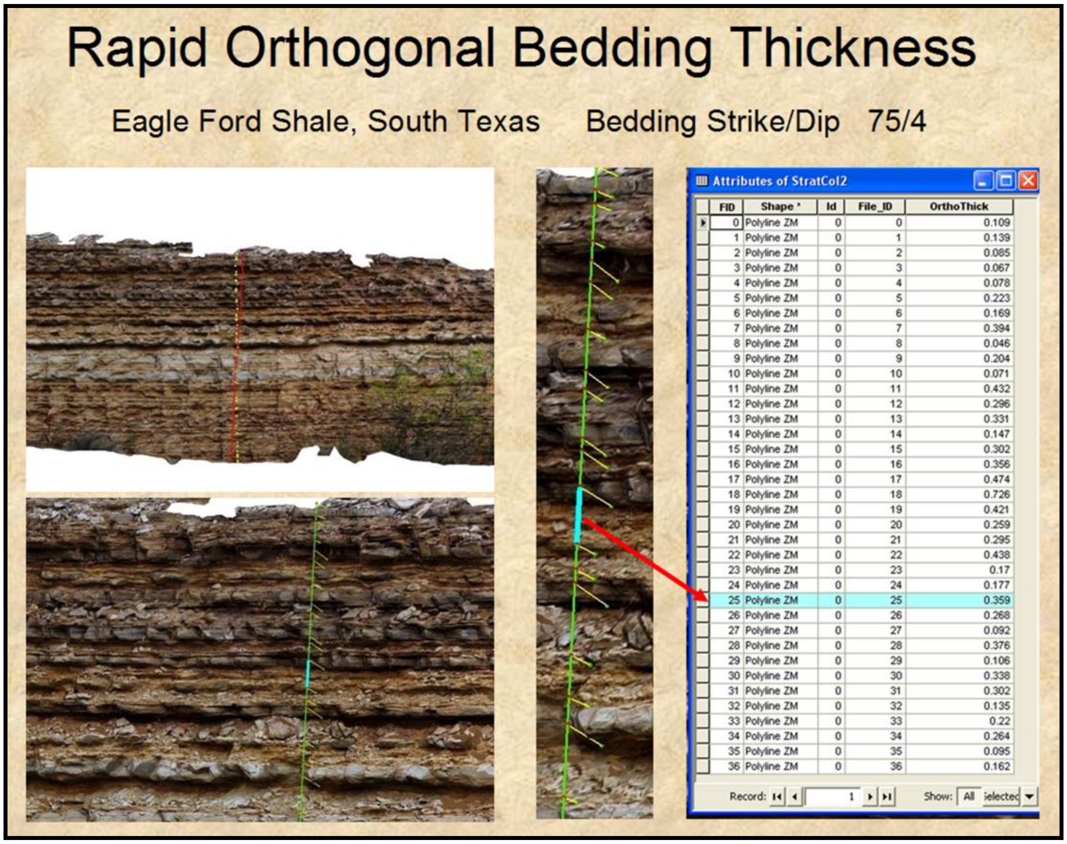
Bed Thickness Measurements
Saved in Attribute Table

Attributes of Thickness

FID	Shape	measName	measID	interval	thickness
796	Polyline ZM	Bed2	235	117	1.333
797	Polyline ZM	Bed2	236	117.5	1.360
798	Polyline ZM	Bed2	237	118	1.381
799	Polyline ZM	Bed2	238	118.5	1.385
800	Polyline ZM	Bed2	239	119	1.371
801	Polyline ZM	Bed2	240	119.5	1.409
802	Polyline ZM	Bed2	241	120	1.453
803	Polyline ZM	Bed2	242	120.5	1.473
804	Polyline ZM	Bed2	243	121	1.466
805	Polyline ZM	Bed2	244	121.5	1.470
806	Polyline ZM	Bed2	245	122	1.444
807	Polyline ZM	Bed2	246	122.5	1.412
808	Polyline ZM	Bed2	247	123	1.392
809	Polyline ZM	Bed2	248	123.5	1.398
810	Polyline ZM	Bed2	249	124	1.420
811	Polyline ZM	Bed2	250	124.5	1.428
812	Polyline ZM	Bed2	251	125	1.432
813	Polyline ZM	Bed2	252	125.5	1.466
814	Polyline ZM	Bed2	253	126	1.479
815	Polyline ZM	Bed2	254	126.5	1.501
816	Polyline ZM	Channel1	1	0	0.003
817	Polyline ZM	Channel1	2	0.1	0.052
818	Polyline ZM	Channel1	3	0.2	0.101
819	Polyline ZM	Channel1	4	0.3	0.144
820	Polyline ZM	Channel1	5	0.4	0.177
821	Polyline ZM	Channel1	6	0.5	0.211
822	Polyline ZM	Channel1	7	0.6	0.244
823	Polyline ZM	Channel1	8	0.7	0.272
824	Polyline ZM	Channel1	9	0.8	0.298
825	Polyline ZM	Channel1	10	0.9	0.321
826	Polyline ZM	Channel1	11	1	0.344
827	Polyline ZM	Channel1	12	1.1	0.367
828	Polyline ZM	Channel1	13	1.2	0.390
829	Polyline ZM	Channel1	14	1.3	0.413
830	Polyline ZM	Channel1	15	1.4	0.432
831	Polyline ZM	Channel1	16	1.5	0.450
832	Polyline ZM	Channel1	17	1.6	0.467
833	Polyline ZM	Channel1	18	1.7	0.481

Down Plunge Cross-Section Trend/Plunge 178 / 4
Bedding Thickness Measured at 0.5m and 0.1m Intervals

Figure 5. Autobed thickness measurement, Eagle Ford Shale.



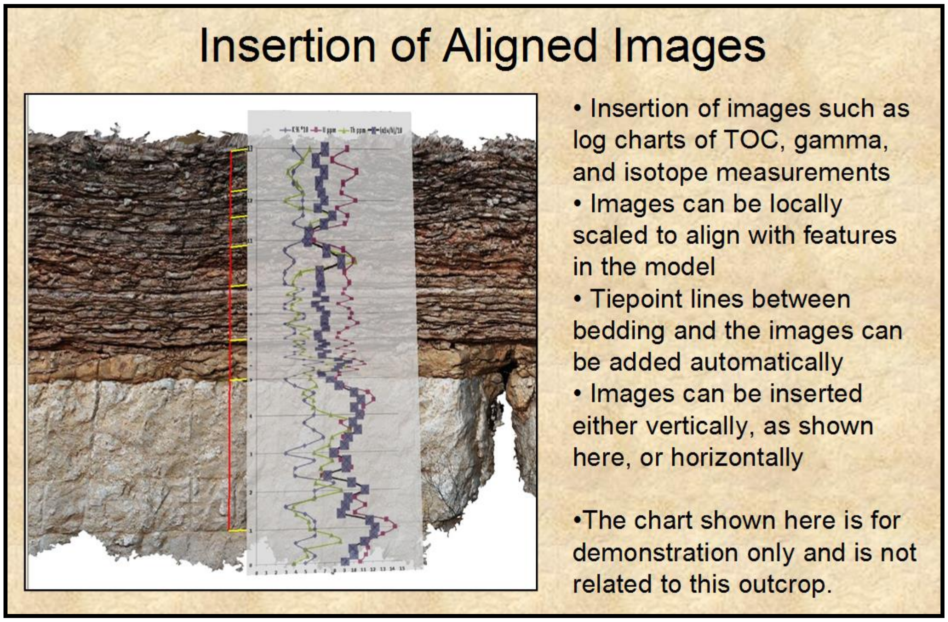
Rapid Orthogonal Bedding Thickness

Eagle Ford Shale, South Texas   Bedding Strike/Dip   75/4

Attributes of StratCol2

FID	Shape *	Id	File_ID	OrthoThick
0	Polyline ZM	0	0	0.109
1	Polyline ZM	0	1	0.139
2	Polyline ZM	0	2	0.085
3	Polyline ZM	0	3	0.067
4	Polyline ZM	0	4	0.078
5	Polyline ZM	0	5	0.223
6	Polyline ZM	0	6	0.169
7	Polyline ZM	0	7	0.394
8	Polyline ZM	0	8	0.046
9	Polyline ZM	0	9	0.204
10	Polyline ZM	0	10	0.071
11	Polyline ZM	0	11	0.432
12	Polyline ZM	0	12	0.296
13	Polyline ZM	0	13	0.331
14	Polyline ZM	0	14	0.147
15	Polyline ZM	0	15	0.302
16	Polyline ZM	0	16	0.356
17	Polyline ZM	0	17	0.474
18	Polyline ZM	0	18	0.726
19	Polyline ZM	0	19	0.421
20	Polyline ZM	0	20	0.259
21	Polyline ZM	0	21	0.295
22	Polyline ZM	0	22	0.438
23	Polyline ZM	0	23	0.17
24	Polyline ZM	0	24	0.177
25	Polyline ZM	0	25	0.359
26	Polyline ZM	0	26	0.268
27	Polyline ZM	0	27	0.092
28	Polyline ZM	0	28	0.376
29	Polyline ZM	0	29	0.106
30	Polyline ZM	0	30	0.338
31	Polyline ZM	0	31	0.302
32	Polyline ZM	0	32	0.135
33	Polyline ZM	0	33	0.22
34	Polyline ZM	0	34	0.264
35	Polyline ZM	0	35	0.095
36	Polyline ZM	0	36	0.162

Figure 6. Rapid Jacob Staff tool, Eagle Ford Shale.



Insertion of Aligned Images

- Insertion of images such as log charts of TOC, gamma, and isotope measurements
- Images can be locally scaled to align with features in the model
- Tiepoint lines between bedding and the images can be added automatically
- Images can be inserted either vertically, as shown here, or horizontally

•The chart shown here is for demonstration only and is not related to this outcrop.

Figure 7. Insertion of aligned images into the model.

A selection of geological symbols has been added to identify different facies on the outcrop model. Figure 8 shows the available symbols on the surface of an overturned section of the Woodford Shale in southern Oklahoma. The geologist places a graphics point on the surface of the model and then edits the properties of the graphics point. The desired symbol is selected and its orientation is adjusted for best appearance on the model surface. All of the available symbols are shown in Figure 8. There is no correlation of these symbols to this outcrop. It was used as the backdrop for the symbols because the excellent coloring and smoothness of the surface highlights the nature of the symbols.

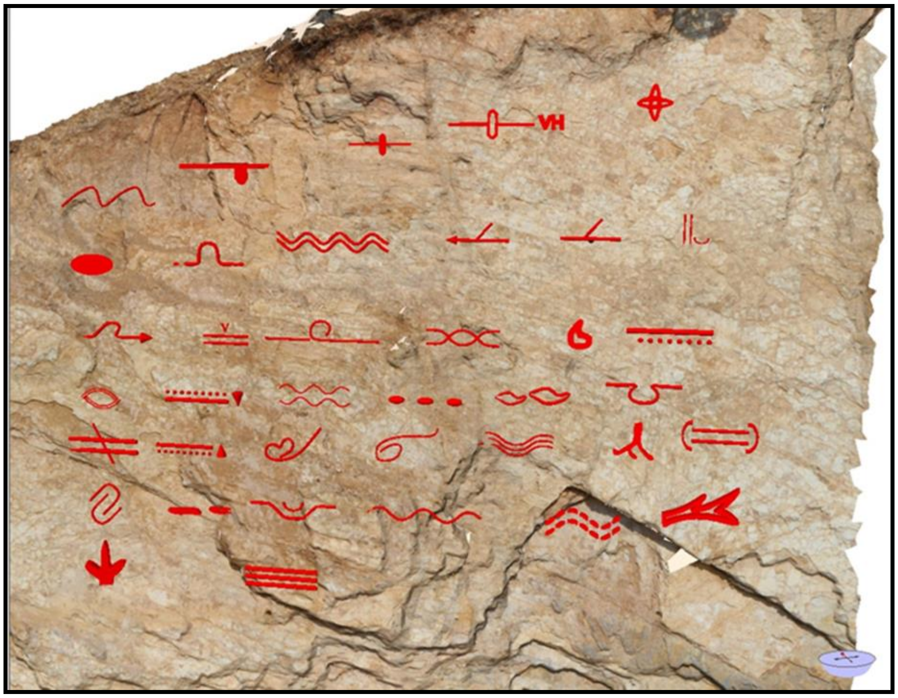


Figure 8. Placement of facies symbols on the surface of the outcrop model, overturned Woodford Shale, Arbuckle Anticline, near Interstate 35, southern Oklahoma.

Conclusions

Photorealistic geological outcrops are detailed replicas of the outcrops in digital format. Viewing and inspection of the outcrops for analysis, training, and explanation is available on standard laptops and PC's using the ESRI ArcGIS based extension GeoAnalysisTools. Measurements of orientation and distance can be quickly accomplished in the digital format. Comprehensive bedding thickness measurements can be made at levels of detail that are impractical using a field study approach. The results of all analysis are saved as standard ESRI shapefiles.

Acknowledgements

Models of the Eagle Ford Shale road cut outcrops were created by the University of Texas at Dallas under contract to Royal Dutch Shell.

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