

APPENDIX 20c

**CLASSIFICATION AND REGRESSION TREE (CART) SENSITIVITY ANALYSIS
PREDICTING
PRODUCTIVE VS. NON-PRODUCTIVE CELLS USING WELL DATA**

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1. INTRODUCTION

This analysis was performed to understand the predictive powers and relationships between seven key geoscience parameters using CART. This statistical method was utilized using JMP Pro 9.0, part of the SAS Predictive Analytics Suite.

The following series of tables document the CART sensitivity analysis exploring all possibilities of the indicated parameters (Table 20c.1) for predicting the productive vs. non-productive nature of a given cell. Each parameter (response variable) is systematically removed from the analysis starting with one variable removed and ending with six out of the seven variables removed, presented in Tables 20c.2 to 20c.7. Parameters considered in the analysis are highlighted in light purple, while if the parameter was used in the analysis, the cell also has a X. The parameter that the analysis first splits on contains a red X. Parameters that have been removed from the analysis are blank (highlighted white).

The R^2 value corresponds to the accuracy of CART to predict productive vs. non-productive cells using the Well Data according to the divisions of the data used. The range of R^2 values results are from 0.055 to 0.665, while all values over **0.6** are bolded. A color scheme (green-yellow-orange-red) was implemented to distinguish the relative range of R^2 values per individual analysis, with red representing high values, and green representing low values. The # of splits was recorded as each analysis was terminated due to the split history curve "leveling out" and the R^2 value not increasing substantially as the analysis continued to split on the remaining data. The analysis was also terminated if the cross-validation curve (a separate automatic analysis performed with a sub-set of the remaining data) was not in agreement with the expressed R^2 value.

Table 20c.1 Geoscience Parameters Description Used in this Analysis.

Parameter	Description
Productive	Cells occurring as incremental depth slices (500m) of well are considered productive (hydrothermal) if they contain known injection or production zones or are considered sub-commercial at that depth. Non-productive cells include all other cells.
<i>Lith</i>	Lithology, specifically referring to a lithologic unit.
<i>Vp</i>	Seismic parameter: P-wave velocity
<i>Resistivity</i>	Magneto-telluric data
<i>Dilatation</i>	Dilatation derived from modeled stress data
<i>VertStress</i>	Vertical Stress: calculated parameter
<i>Grav_Mag</i>	Combined Gravity and Magnetic inferred Lithologic Unit
<i>Temp</i>	Temperature derived from AltaRock thermal models (see Plates 1 and 2)

Table 20c.2. CART Sensitivity Analysis for Prediction of Productive vs. Non-Productive Cells Using Well Data and Removing One Variable for Each Case Analyzed.

	Variable Considered
	Variable Removed

Predictor	Response Variables (X Used, X First Split)							R ² Value	Splits
Productive	Vp	Resistivity	Lithology	Dilatation	VertStress	Grav_Mag	Temp		
Case 1: All Variables Considered with each parameter systematically removed									
---	X	X	X	X	X	X	X	0.625	6
---	X	X	X		X			0.617	6
---	X		X		X			0.589	5
---	X	X	X					0.528	4
---	X	X	X		X			0.561	6
---				X	X	X		0.447	5
---			X	X	X			0.527	4
---		X	X	X	X			0.524	5

Table 20c.3. CART Sensitivity Analysis for Prediction of Productive vs. Non-Productive Cells Using Well Data and Removing Two Variables for Each Case Analyzed. The Base Case has One Variable Removed.

	Variable Considered
	Variable Removed
	Baseline Case

Predictor	Response Variables (X Used, X First Split)							R ² Value	Splits
Productive	Vp	Resistivity	Lithology	Dilatation	VertStress	Grav_Mag	Temp		
Case 1. All Variables excluding Temperature (Temp) + one variable									
	X	X	X		X			0.617	6
	X	X	X		X			0.647	8
	X	X	X	X				0.615	6
	X	X	X		X	X		0.576	6
				X	X	X		0.442	4
	X		X		X			0.663	7
		X	X	X	X			0.574	6
Case 2. All Variables excluding Gravity and Magnetic inferred Lithology (Grav_Mag) + one variable									
	X		X		X			0.589	5
	X	X	X		X			0.647	8
		X	X	X				0.507	5
	X	X	X		X			0.637	8
	X			X	X			0.431	6
			X	X	X			0.534	4
		X	X	X	X			0.534	5
Case 3. All Variables excluding Vertical Stress (VertStress) + one variable									
	X	X	X					0.528	4
	X	X	X	X				0.615	6
		X	X	X				0.507	5
	X	X	X			X	X	0.540	6
	X	X		X		X		0.363	6
	X		X					0.583	4
		X	X	X		X		0.581	7
Case 4. All Variables excluding Dilatation + one variable									
	X	X	X		X			0.561	6
	X	X	X		X	X		0.576	6
	X	X	X		X			0.637	8
	X	X	X			X	X	0.540	6
	X	X			X	X		0.512	8
	X		X		X			0.607	5
		X	X		X			0.460	4
Case 5. All Variables excluding Lithology + one variable									
				X	X	X		0.447	5
				X	X	X		0.442	4
	X			X	X			0.431	6
	X	X		X		X		0.363	6
	X	X			X	X		0.512	8
	X			X	X	X		0.498	7

Table 20c.3. CART Sensitivity Analysis for Prediction of Productive vs. Non-Productive Cells Using Well Data and Removing Two Variables for Each Case Analyzed. The Base Case has One Variable Removed.

	Variable Considered
	Variable Removed
	Baseline Case

Predictor	Response Variables (X Used, X First Split)							R ² Value	Splits
Productive	Vp	Resistivity	Lithology	Dilatation	VertStress	Grav_Mag	Temp		
Case 6. All Variables excluding Resistivity + one variable									
			X	X	X			0.527	4
	X		X		X			0.663	7
			X	X	X			0.534	4
	X		X					0.583	4
	X		X		X			0.607	5
	X			X	X	X		0.498	7
			X	X	X	X		0.594	7
Case 7. All Variables excluding P-wave Velocity (Vp) + one variable									
		X	X	X	X			0.524	5
		X	X	X	X			0.574	6
		X	X	X	X			0.534	5
		X	X	X		X		0.581	7
		X	X		X			0.460	4
				X	X	X		0.458	5
			X	X	X	X		0.594	7

Table 20c.4. CART Sensitivity Analysis for Prediction of Productive vs. Non-Productive Cells Using Well Data and Removing Three Variables for Each Case Analyzed. The response variable (parameter) CSC was used instead of Lithology. This produced lower overall R^2 values and the determination that the parameter (CSC) is not useful in predicting productive vs. non-productive cells. The remaining analyses used lithology as a primary response variable, and did not consider CSC.

Variable
Considered

Variable Removed

Predictor	Response Variables (X Used, X First Split)							R ² Value	Splits
Productive	Vp	Resistivity	CSC	Dilatation	VertStress	Grav_Mag	Temp		
Case 1. Removal of Temperature (Temp) plus two variables									
---	X	X	X	X				0.384	5
---		X	X		X			0.604	8
---		X		X	X			0.665	8
---				X	X			0.664	8
---				X	X			0.663	8
---	X	X				X		0.403	5
---	X	X		X		X		0.433	6
---	X			X		X		0.368	6
---		X		X		X		0.376	6
---		X			X	X		0.635	8
---			X		X	X		0.621	8
---		X			X	X		0.636	8
---				X	X			0.662	8
---		X		X	X			0.663	8
---				X	X			0.664	8
Case 2. Removal of Gravity and Magnetic inferred Lithology (Grav_Mag) plus two variables									
---	X	X	X	X				0.384	5
---		X	X		X			0.604	8
---		X		X	X			0.665	8
---				X	X			0.664	8
---				X	X			0.663	8
---	X	X					X	0.365	4
---	X	X		X				0.383	4
---	X			X				0.407	6
---		X		X			X	0.408	7
---		X			X			0.611	8
---			X		X			0.578	7
---		X	X		X			0.615	8
---				X	X			0.653	7
---				X	X			0.629	6
---				X	X			0.654	7
Case 3. Removal of Vertical Stress (VertStress) plus two variables									
---	X	X	X	X				0.384	5
---	X	X				X		0.403	5
---	X	X		X		X		0.433	6

Table 20c.4. CART Sensitivity Analysis for Prediction of Productive vs. Non-Productive Cells Using Well Data and Removing Three Variables for Each Case Analyzed. The response variable (parameter) CSC was used instead of Lithology. This produced lower overall R^2 values and the determination that the parameter (CSC) is not useful in predicting productive vs. non-productive cells. The remaining analyses used lithology as a primary response variable, and did not consider CSC.

Variable Considered

Variable Removed

Predictor	Response Variables (X Used, X First Split)							R^2 Value	Splits
Productive	Vp	Resistivity	CSC	Dilatation	VertStress	Grav_Mag	Temp		
---	X			X		X		0.368	6
---		X		X		X		0.376	6
---	X	X					X	0.365	4
---	X	X		X				0.383	4
---	X			X				0.407	6
---		X		X			X	0.408	7
---	X	X				X	X	0.423	7
---	X		X			X		0.385	4
---		X				X	X	0.367	5
---	X			X		X		0.416	4
---		X		X		X	X	0.388	5
---				X		X	X	0.393	5
Case 4. Removal of Dilatation plus two variables									
---		X	X		X			0.604	8
---	X	X				X		0.403	5
---		X			X	X		0.635	8
---			X		X	X		0.621	8
---		X			X	X		0.636	8
---	X	X					X	0.365	4
---		X			X			0.611	8
---			X		X			0.578	7
---		X	X		X			0.615	8
---	X	X				X	X	0.423	7
---	X		X			X		0.385	4
---		X				X	X	0.367	5
---					X	X		0.555	5
---		X			X	X		0.553	4
---					X	X		0.523	4
Case 5. Removal of Lithology plus two variables									
---		X		X	X			0.665	8
---	X	X		X		X		0.433	6
---		X			X	X		0.635	8
---				X	X			0.662	8
---		X		X	X			0.663	8
---	X	X		X				0.383	4
---		X			X			0.611	8
---				X	X			0.653	7
---				X	X			0.629	6
---	X	X				X	X	0.423	7

Table 20c.4. CART Sensitivity Analysis for Prediction of Productive vs. Non-Productive Cells Using Well Data and Removing Three Variables for Each Case Analyzed. The response variable (parameter) CSC was used instead of Lithology. This produced lower overall R² values and the determination that the parameter (CSC) is not useful in predicting productive vs. non-productive cells. The remaining analyses used lithology as a primary response variable, and did not consider CSC.

Variable Considered

Variable Removed

Predictor	Response Variables (X Used, X First Split)							R ² Value	Splits
Productive	Vp	Resistivity	CSC	Dilatation	VertStress	Grav_Mag	Temp		
---	X			X		X		0.416	4
---		X		X		X	X	0.388	5
---					X	X		0.555	5
---		X			X	X		0.553	4
---				X	X			0.654	7
Case 6. Removal of Resistivity plus two variables									
---				X	X			0.664	8
---	X			X		X		0.368	6
---			X		X	X		0.621	8
---				X	X			0.662	8
---				X	X			0.664	8
---	X			X				0.407	6
---			X		X			0.578	7
---				X	X			0.653	7
---				X	X			0.654	7
---	X		X			X		0.385	4
---	X			X		X		0.416	4
---				X		X	X	0.393	5
---					X	X		0.555	5
---					X	X		0.523	4
---				X	X			0.654	7
Case 7. Removal of P-wave velocity (Vp) plus two variables									
---				X	X			0.663	8
---		X		X		X		0.376	6
---		X			X	X		0.636	8
---		X		X	X			0.663	8
---				X	X			0.664	8
---		X		X			X	0.408	7
---		X	X		X			0.615	8
---				X	X			0.629	6
---				X	X			0.654	7
---		X				X	X	0.367	5
---		X		X		X	X	0.388	5
---				X		X	X	0.393	5
---		X			X	X		0.553	4
---					X	X		0.523	4
---				X	X			0.654	7

Table20c.5. CART Sensitivity Analysis for Prediction of Productive vs. Non-Productive Cells Using Well Data and Removing Four Variables for Each Case Analyzed.

Variable Considered

Variable Removed

Predictor	Response Variables (X Used, X First Split)							R ² Value	Splits
Productive	Vp	Resistivity	Lithology	Dilatation	VertStress	Grav_Mag	Temp		
Case 1. Removal of Temperature plus three other variables									
---	X	X	X					0.594	6
---	X	X		X				0.425	7
---	X		X	X				0.598	5
---		X	X	X				0.502	4
---	X	X			X			0.496	8
---	X		X		X			0.648	6
---		X	X		X			0.596	7
---	X			X	X			0.486	7
---				X	X			0.493	5
---			X	X	X			0.526	4
---	X					X		0.320	4
---	X		X					0.567	4
---		X	X					0.450	3
---	X			X		X		0.394	5
---				X		X		0.395	3
---			X	X		X		0.478	3
---	X				X	X		0.485	6
---		X			X	X		0.425	6
---			X		X	X		0.571	5
---				X	X	X		0.439	4
Case 2. Removal of Grav_Mag plus three other variables									
---	X	X	X					0.594	6
---	X	X		X				0.425	7
---	X		X	X				0.598	5
---		X	X	X				0.502	4
---	X	X			X			0.496	8
---	X		X		X			0.648	6
---		X	X		X			0.596	7
---	X			X	X			0.486	7
---				X	X			0.493	5
---			X	X	X			0.526	4
---	X	X						0.334	5
---	X		X					0.505	3
---		X	X				X	0.445	3
---	X			X			X	0.357	5
---		X		X				0.281	5
---			X	X			X	0.525	7
---	X				X			0.465	7
---		X			X			0.361	4
---			X		X		X	0.473	4
---				X	X			0.484	5

Table 20C.5. CART Sensitivity Analysis for Prediction of Productive vs. Non-Productive Cells Using Well Data and Removing Four Variables for Each Case Analyzed

Variable Considered

Variable Removed

Predictor	Response Variables (X Used, X First Split)							R ² Value	Splits
Productive	Vp	Resistivity	Lithology	Dilatation	VertStress	Grav_Mag	Temp		
Case 3. Removal of Vertical Stress plus three other variables									
---	X	X	X					0.594	6
---	X	X		X				0.425	7
---	X		X	X				0.598	5
---		X	X	X				0.502	4
---	X					X		0.320	4
---	X		X					0.567	4
---		X	X					0.450	3
---	X			X		X		0.394	5
---				X		X		0.395	3
---			X	X		X		0.478	3
---	X	X						0.334	5
---	X		X					0.505	3
---		X	X				X	0.445	3
---	X			X			X	0.357	5
---		X		X				0.281	5
---			X	X			X	0.525	7
---	X					X		0.325	4
---		X				X		0.206	5
---			X			X	X	0.494	4
---				X		X		0.352	4
Case 4. Removal of Dilatation plus three other variables									
---	X	X	X					0.594	6
---	X	X			X			0.496	8
---	X		X		X			0.648	6
---		X	X		X			0.596	7
---	X					X		0.320	4
---	X		X					0.567	4
---		X	X					0.450	3
---	X				X	X		0.485	6
---		X			X	X		0.425	6
---			X		X	X		0.571	5
---	X	X						0.334	5
---	X		X					0.505	3
---		X	X				X	0.445	3
---	X				X			0.465	7
---		X			X			0.361	4
---			X		X		X	0.473	4
---	X					X		0.325	4
---		X				X		0.206	5
---			X			X	X	0.494	4

Table20c.5. CART Sensitivity Analysis for Prediction of Productive vs. Non-Productive Cells Using Well Data and Removing Four Variables for Each Case Analyzed.

Variable Considered

Variable Removed

Predictor	Response Variables (X Used, X First Split)							R ² Value	Splits
Productive	Vp	Resistivity	Lithology	Dilatation	VertStress	Grav_Mag	Temp		
---					X	X	X	0.437	6
Case 5. Removal of Lithology plus three other variables									
---	X	X		X				0.425	7
---	X	X			X			0.496	8
---	X			X	X			0.486	7
---				X	X			0.493	5
---	X					X		0.320	4
---	X			X		X		0.394	5
---				X		X		0.395	3
---	X				X	X		0.485	6
---		X			X	X		0.425	6
---				X	X	X		0.439	4
---	X	X						0.334	5
---	X			X			X	0.357	5
---		X		X				0.281	5
---	X				X			0.465	7
---		X			X			0.361	4
---				X	X			0.484	5
---	X					X		0.325	4
---		X				X		0.206	5
---				X		X		0.352	4
---					X	X	X	0.437	6
Case 6. Removal of Resistivity plus three other variables									
---	X		X	X				0.598	5
---	X		X		X			0.648	6
---	X			X	X			0.486	7
---			X	X	X			0.526	4
---	X		X					0.567	4
---	X			X		X		0.394	5
---			X	X		X		0.478	3
---	X				X	X		0.485	6
---			X		X	X		0.571	5
---				X	X	X		0.439	4
---	X		X					0.505	3
---	X			X			X	0.357	5
---			X	X			X	0.525	7
---	X				X			0.465	7
---			X		X		X	0.473	4
---				X	X			0.484	5
---	X					X		0.325	4
---			X			X	X	0.494	4

Table 20c.5. CART Sensitivity Analysis for Prediction of Productive vs. Non-Productive Cells Using Well Data and Removing Four Variables for Each Case Analyzed.

Table20c.5. CART Sensitivity Analysis for Prediction of Productive vs. Non-Productive Cells Using Well Data and Removing Four Variables for Each Case Analyzed.								Variable Considered	
								Variable Removed	
Predictor	Response Variables (X Used, X First Split)							R ² Value	Splits
Productive	Vp	Resistivity	Lithology	Dilatation	VertStress	Grav_Mag	Temp		
---				X		X		0.352	4
---					X	X	X	0.437	6
Case 7. Removal of Vp plus three other variables									
---		X	X	X				0.502	4
---		X	X		X			0.596	7
---				X	X			0.493	5
---			X	X	X			0.526	4
---		X	X					0.450	3
---				X		X		0.395	3
---			X	X		X		0.478	3
---		X			X	X		0.425	6
---			X		X	X		0.571	5
---				X	X	X		0.439	4
---		X	X				X	0.445	3
---		X		X				0.281	5
---			X	X			X	0.525	7
---		X			X			0.361	4
---			X		X		X	0.473	4
---				X	X			0.484	5
---		X				X		0.206	5
---			X			X	X	0.494	4
---				X		X		0.352	4
---					X	X	X	0.437	6

Table 20c.6. CART Sensitivity Analysis for Prediction of Productive vs. Non-Productive Cells Using Well Data and Removing Five Variables for Each Case Analyzed.

	Variable Considered
	Variable Removed

Predictor	Response Variables (X Used, X First Split)							R ² Value	Splits
Productive	Vp	Resistivity	Lithology	Dilatation	VertStress	Grav_Mag	Temp		
Case 1. Removal of Temperature plus four other variables									
---	X	X						0.358	6
---	X		X					0.550	4
---		X	X					0.484	3
---	X			X				0.350	5
---		X		X				0.223	3
---			X	X				0.534	4
---	X				X			0.427	6
---		X			X			0.485	8
---			X		X			0.587	6
---				X	X			0.513	6
---	X					X		0.395	7
---		X				X		0.261	4
---			X			X		0.458	3
---				X		X		0.282	3
---					X	X		0.500	7
Case 2. Removal of Grav_Mag plus four other variables									
---	X	X						0.358	6
---	X		X					0.550	4
---		X	X					0.484	3
---	X			X				0.350	5
---		X		X				0.223	3
---			X	X				0.534	4
---	X				X			0.427	6
---		X			X			0.485	8
---			X		X			0.587	6
---				X	X			0.513	6
---	X						X	0.305	4
---		X						0.160	3
---			X				X	0.429	2
---				X			X	0.154	3
---					X		X	0.315	3
Case 3. Removal of Vertical Stress plus four other variables									
---	X	X						0.358	6
---	X		X					0.550	4
---		X	X					0.484	3
---	X			X				0.350	5
---		X		X				0.223	3
---			X	X				0.534	4
---	X					X		0.395	7

Table 20c.6. CART Sensitivity Analysis for Prediction of Productive vs. Non-Productive Cells Using Well Data and Removing Five Variables for Each Case Analyzed.

								Variable Considered	Variable Removed
Predictor	Response Variables (X Used, X First Split)							R ² Value	Splits
Productive	Vp	Resistivity	Lithology	Dilatation	VertStress	Grav_Mag	Temp		
---		X				X		0.261	4
---			X			X		0.458	3
---				X		X		0.282	3
---	X						X	0.305	4
---		X						0.160	3
---			X				X	0.429	2
---				X			X	0.154	3
---						X	X	0.167	2
Case 4. Removal of Dilatation plus four other variables									
---	X	X						0.358	6
---	X		X					0.550	4
---		X	X					0.484	3
---	X				X			0.427	6
---		X			X			0.485	8
---			X		X			0.587	6
---	X					X		0.395	7
---		X				X		0.261	4
---			X			X		0.458	3
---					X	X		0.500	7
---	X						X	0.305	4
---		X						0.160	3
---			X				X	0.429	2
---					X		X	0.315	3
---						X	X	0.167	2
Case 5. Removal of Lithology plus four other variables									
---	X	X						0.358	6
---	X			X				0.350	5
---		X		X				0.223	3
---	X				X			0.427	6
---		X			X			0.485	8
---				X	X			0.513	6
---	X					X		0.395	7
---		X				X		0.261	4
---				X		X		0.282	3
---					X	X		0.500	7
---	X						X	0.305	4
---		X						0.160	3
---				X			X	0.154	3
---					X		X	0.315	3
---						X	X	0.167	2
Case 6. Removal of Resistivity plus four other variables									
---	X		X					0.550	4
---	X			X				0.350	5
---			X	X				0.534	4

Table 20c.6. CART Sensitivity Analysis for Prediction of Productive vs. Non-Productive Cells Using Well Data and Removing Five Variables for Each Case Analyzed.

								Variable Considered
								Variable Removed
Predictor	Response Variables (X Used, X First Split)							
Productive	Vp	Resistivity	Lithology	Dilatation	VertStress	Grav_Mag	Temp	R ² Value
---	X				X			0.427
---			X		X			0.587
---				X	X			0.513
---	X					X		0.395
---			X			X		0.458
---				X		X		0.282
---					X	X		0.500
---	X						X	0.305
---			X				X	0.429
---				X			X	0.154
---					X		X	0.315
---						X	X	0.167
Case 7. Removal of Vp plus four other variables								
---		X	X					0.484
---		X		X				0.223
---			X	X				0.534
---		X			X			0.485
---			X		X			0.587
---				X	X			0.513
---		X				X		0.261
---			X			X		0.458
---				X		X		0.282
---					X	X		0.500
---		X						0.160
---			X				X	0.429
---				X			X	0.154
---					X		X	0.315
---						X	X	0.167

Table 20c.7. CART Sensitivity Analysis for Prediction of Productive vs. Non-Productive Cells Using Well Data and Removing Six Variables for Each Case

	Variable Considered
	Variable Removed

Predictor	Response Variables (X Used, X First Split)							R ² Value	Splits
Productive	Vp	Resistivity	Lithology	Dilatation	VertStress	Grav_Mag	Temp		
Case 1. Removal of six variables systematically									
---							X	0.055	2
---						X		0.156	2
---					X			0.389	4
---				X				0.282	3
---			X					0.457	4
---		X						0.156	4
---	X							0.29	4