The Association between Mars Crater Distance from Equator and Crater Diameter and Depth

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Introduction

Mars craters come in all shapes and sizes. They also exhibit a wide array of characteristics. Reason would indicate that the diameter of a crater and its depth would be positively related--bigger craters should be deeper--but little is known about the size of a crater in relationship to its other characteristics. It is possible that other factors, such as distance of a crater from the equator, may be related to its size.

Research Questions

1. Is crater depth associated with its diameter.
2. Is crater diameter associated with its position relative to the equator.
3. Is crater depth associated with its position relative to the equator.

Methods

Sample

- All craters on Mars (378,540) with diameters greater than or equal to 1 km. as compiled by Stuart Robbins.

- Dr. Robbins compiled the Mars global crater database while pursuing his Ph.D. in Geophysics from the University of Colorado.
- The Mars global database was published as part of Dr. Robbins' thesis Planetary "Surface Properties, Cratering Physics, and the Volcanic History of Mars from a New Global Martian Crater Database" in 2011.

Measures

- Crater latitude was calculated from a best-fit derived center and was measured in decimal degrees North.
- Diameter was measured in kilometers from the derived center to the rim vertices.
- Depth was measured in kilometers from the crater rim to the lowest elevation of the crater floor.
- For some calculations craters were separated into groups representing ten-degree "bands" of latitude.
- For some calculation crater latitude was rounded down to the nearest whole degree latitude.

```
> summary(LATITUDE_CIRCLE_IMAGE)
   Min. 1st Qu.  Median    Mean 3rd Qu.    Max.
-86.700 -30.940 -10.080  -7.199  17.220  85.700
> summary(DIAM_CIRCLE_IMAGE)
    Min.  1st Qu.   Median     Mean  3rd Qu.     Max.
   1.000    1.180    1.530    3.557    2.550 1164.000
> summary(DEPTH_RIMFLOOR_TOPOG)
    Min.  1st Qu.   Median     Mean  3rd Qu.     Max.
-0.42000  0.00000  0.00000  0.07584  0.00000  4.95000
> stat.desc(LATITUDE_CIRCLE_IMAGE)
      nbr.val      nbr.null        nbr.na           min           max
 3.843430e+05  7.000000e+00  0.000000e+00 -8.670000e+01  8.570200e+01
       range           sum        median          mean       SE.mean
 1.724020e+02 -2.766965e+06 -1.007900e+01 -7.199209e+00  5.421203e-02
 CI.mean.0.95           var       std.dev      coef.var
 1.062540e-01  1.129563e+03  3.360897e+01 -4.668425e+00
> stat.desc(DIAM_CIRCLE_IMAGE)
     nbr.val     nbr.null       nbr.na          min          max        range
3.843430e+05 0.000000e+00 0.000000e+00 1.000000e+00 1.164220e+03 1.163220e+03
         sum       median         mean      SE.mean CI.mean.0.95          var
1.366988e+06 1.530000e+00 3.556686e+00 1.385908e-02 2.716338e-02 7.382234e+01
     std.dev     coef.var
8.591993e+00 2.415730e+00
> stat.desc(DEPTH_RIMFLOOR_TOPOG)
      nbr.val      nbr.null        nbr.na           min           max
 3.843430e+05  3.075290e+05  0.000000e+00 -4.200000e-01  4.950000e+00
       range           sum        median          mean       SE.mean
 5.370000e+00  2.914763e+04  0.000000e+00  7.583755e-02  3.573128e-04
 CI.mean.0.95           var       std.dev      coef.var
 7.003225e-04  4.907001e-02  2.215175e-01  2.920948e+00
```

Figure 1: Summary statistics for crater latitude (LATITUDE_CIRCLE_IMAGE), diameter (DIAM_CIRCLE_IMAGE), and depth (DEPTH_RIMFLOOR_TOPOG) calculated with R (functions summary and stat.desc).

The CORR Procedure

3 Variables:	DIAM_CIRCLE_IMAGE	DEPTH_RIMFLOOR_TOPOG	LATITUDE_CIRCLE_IMAGE

Simple Statistics

Variable	N	Mean	Std Dev	Sum	Minimum	Maximum	Label
DIAM_CIRCLE_IMAGE	384343	3.55669	8.59199	1366988	1.00000	1164	Crater Diameter (in km)
DEPTH_RIMFLOOR_TOPOG	384343	0.07584	0.22152	29148	-0.42000	4.95000	Average Elevation of Crater Rim (in km)
LATITUDE_CIRCLE_IMAGE	384343	-7.19921	33.60897	-2766965	-86.70000	85.70200	Latitude of Crater Center

Pearson Correlation Coefficients, N = 384343
Prob > |r| under H0: Rho=0

	DIAM_CIRCLE_IMAGE	DEPTH_RIMFLOOR_TOPOG
DIAM_CIRCLE_IMAGE	1.00000	0.58671
Crater Diameter (in km)		<.0001
DEPTH_RIMFLOOR_TOPOG	0.58671	1.00000
Average Elevation of Crater Rim (in km)	<.0001	
LATITUDE_CIRCLE_IMAGE	-0.05794	-0.04288
Latitude of Crater Center	<.0001	<.0001

Pearson Correlation Coefficients, N = 384343 Prob > |r| under H0: Rho=0
LATITUDE_CIRCLE_IMAGE
-0.05794
<.0001
-0.04288
<.0001
1.00000

Figure 2: Correlation of crater latitude (LATITUDE_CIRCLE_IMAGE), diameter (DIAM_CIRCLE_IMAGE), and depth (DEPTH_RIMFLOOR_TOPOG). Proc Correlation procedure. Interpret Pearson Correlation Coefficients.

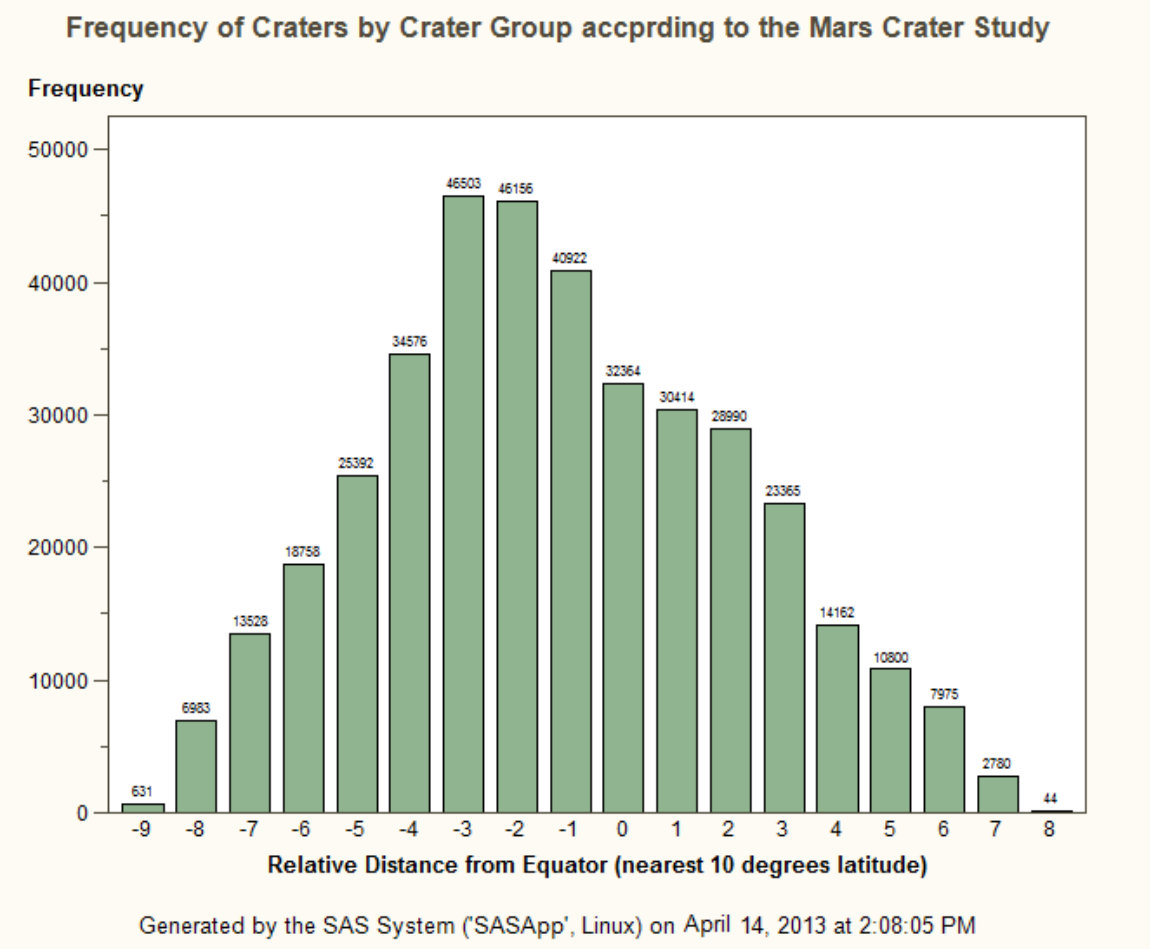
Results

Univariate

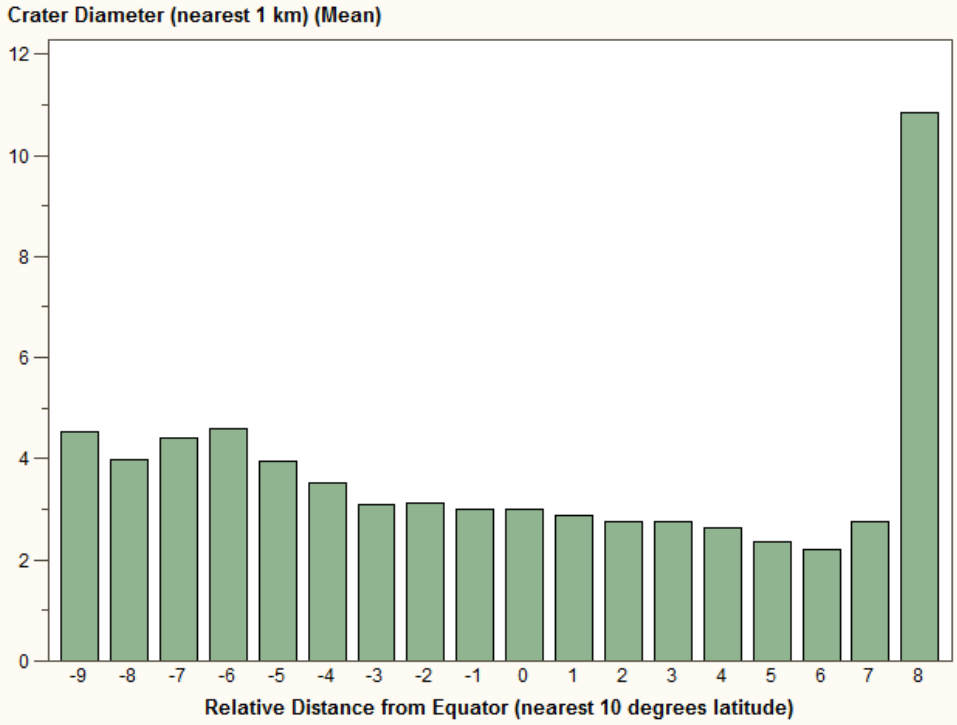
- The average crater diameter is 3.56 km. (s.d. 8.59)
- The average crater depth is 0.0758 km. (s.d. 0.2215)
- The average crater latitude is 7.20 degrees South (s.d. 3.36) showing a slight skew toward the Southern hemisphere.

Bivariate

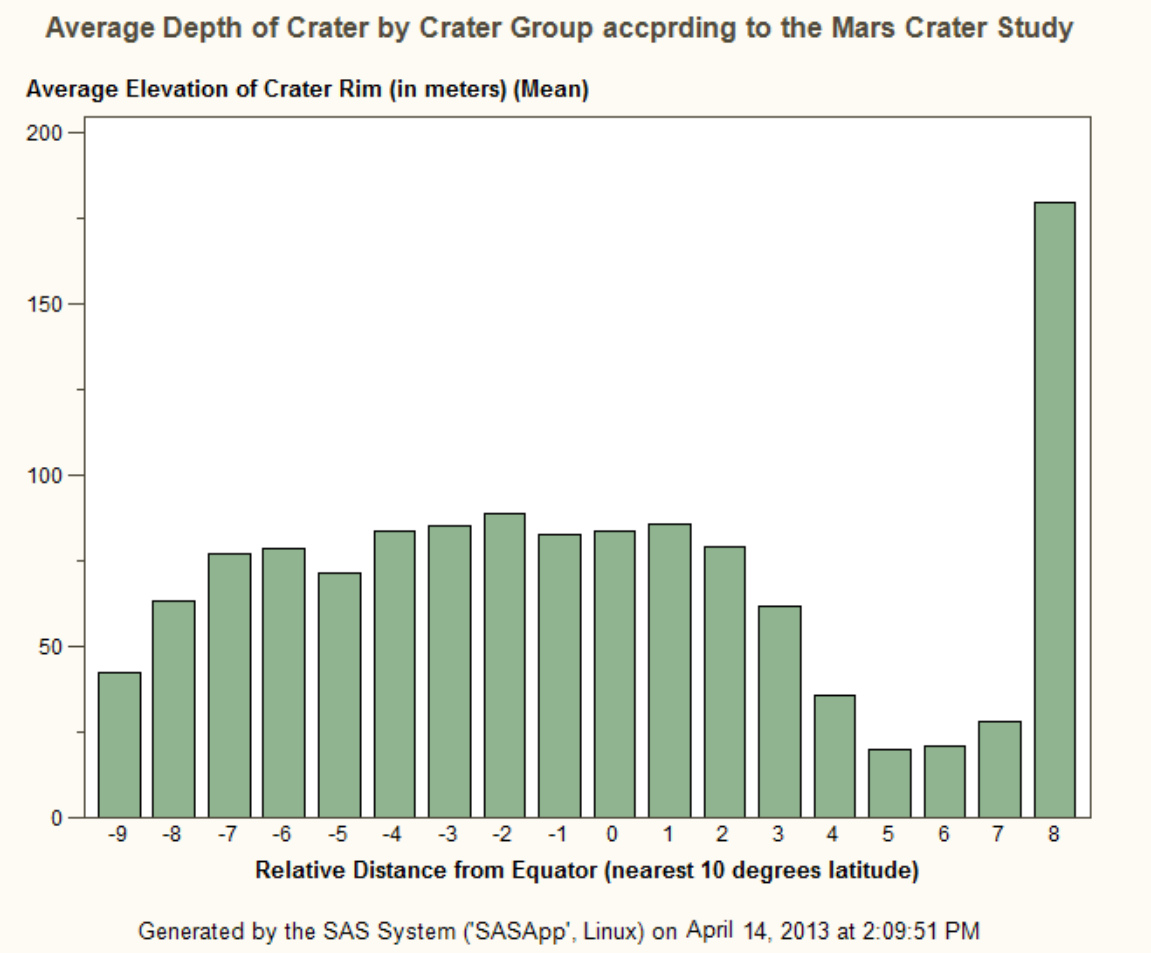
- As expected, analysis showed a positive correlation between crater diameter and depth (corr. 0.58671, $p < 0.0001$), suggesting that 34.4% of the depth variance can be explained by diameter. That is, bigger craters tend to be deeper craters.
- There is a minimal but significant negative correlation between crater latitude and diameter (corr. -0.05794 $p < 0.0001$). That is, craters tend to be slightly wider as they get nearer to the equator.
- There is a minimal but significant negative correlation between crater latitude and depth (corr. -0.04288 $p < 0.0001$). That is, craters tend to be slightly deeper as they get nearer to the equator.



Average Approximate Diameter of Crater by Crater Group accprding to the Mars Crater Study



Generated by the SAS System ('SASApp', Linux) on April 14, 2013 at 2:00:15 PM



Discussion

What might the results mean?

- The distance of a crater from the Mars equator seems to have a small but measurable relationship to its diameter and depth.

Strength

- Results are based on a comprehensive and statistically complete study of over 380,000 Mars craters.

Limitations

- Crater diameter and depth had to be calculated based upon a number of factors related to the crater rim. Although mathematically consistent, these values are approximations. The small correlations found in this study could be the result of measuring errors.

Recommended Future Research

- Further research is needed to determine whether relationships exist between any other characteristics of Mars craters.

The UNIVARIATE Procedure

Variable: NEAREST_LATITUDE (Relative Distance from Equator (nearest 1 degree latitude))

Moments			
N	384343	Sum Weights	384343
Mean	-7.6983346	Sum Observations	-2958801
Std Deviation	33.6107816	Variance	1129.68464
Skewness	0.19148212	Kurtosis	-0.5437515
Uncorrected SS	456963095	Corrected SS	434185255
Coeff Variation	-436.59809	Std Error Mean	0.05421496

Basic Statistical Measures			
Location		Variability	
Mean	-7.6983	Std Deviation	33.61078
Median	-11.0000	Variance	1130
Mode	-22.0000	Range	172.00000
		Interquartile Range	48.00000

Tests for Location: Mu0=0				
Test	Statistic		p Value	
Student's t	t	-141.997	Pr > |t|	<.0001
Sign	M	-42949.5	Pr >= |M|	<.0001
Signed Rank	S	-9.501E9	Pr >= |S|	<.0001

Quantiles (Definition 5)	
Quantile	Estimate
100% Max	85
99%	68
95%	52
90%	38
75% Q3	17
50% Median	-11
25% Q1	-31
10%	-51
5%	-62
1%	-74
0% Min	-87

Extreme Observations			
Lowest		Highest	
Value	Obs	Value	Obs
-87	373860	84	68
-87	372616	85	78
-86	381586	85	209
-86	381146	85	281
-86	381141	85	3811

Figure 3: Mean crater latitude (rounded down to nearest whole degree) and standard deviation (quantitative, ordered variable). Variable named NEAREST_LATITUDE. Proc Univariate Procedure.

The UNIVARIATE Procedure

Variable: APPROX_DIAMETER (Crater Diameter (nearest 1 km))

Moments			
N	384343	Sum Weights	384343
Mean	3.18584181	Sum Observations	1224456
Std Deviation	8.56024026	Variance	73.2777133
Skewness	23.750816	Kurtosis	1928.47299
Uncorrected SS	32064626	Corrected SS	28163702.9
Coeff Variation	268.696337	Std Error Mean	0.01380786

Basic Statistical Measures			
Location		Variability	
Mean	3.185842	Std Deviation	8.56024
Median	1.000000	Variance	73.27771
Mode	1.000000	Range	1163
		Interquartile Range	1.00000

Tests for Location: Mu0=0				
Test	Statistic		p Value	
Student's t	t	230.7266	Pr > |t|	<.0001
Sign	M	192171.5	Pr >= |M|	<.0001
Signed Rank	S	3.693E10	Pr >= |S|	<.0001

Quantiles (Definition 5)	
Quantile	Estimate
100% Max	1164
99%	37
95%	12
90%	6
75% Q3	2
50% Median	1
25% Q1	1
10%	1
5%	1
1%	1
0% Min	1

Extreme Observations			
Lowest		Highest	
Value	Obs	Value	Obs
1	384343	467	227410
1	384342	512	208706
1	384341	624	188255
1	384340	1096	188254
1	384339	1164	370653

Figure 4: Mean crater diameter (rounded down to nearest whole kilometer) and standard deviation (quantitative, ordered variable). Variable named APPROX_DIAMETER. Proc Univariate procedure.

The ANOVA Procedure

Dependent Variable: DEPTH_RIMFLOOR_TOPOG Average Elevation of Crater Rim (in km)

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	1	22.11186	22.11186	451.15	<.0001
Error	384341	18837.55491	0.04901		
Corrected Total	384342	18859.66676			

R-Square	Coeff Var	Root MSE	DEPTH_RIMFLOOR_TOPOG Mean
0.001172	291.9239	0.221388	0.075838

Source	DF	Anova SS	Mean Square	F Value	Pr > F
HEMISPHERE	1	22.11185935	22.11185935	451.15	<.0001

Figure 5: Relationship of crater hemisphere (categorical variable) and crater depth (quantitative variable). Proc ANOVA procedure. Interpret columns F Value and P Value(451.15, 0.0001).

The ANOVA Procedure

Dependent Variable: DIAM_CIRCLE_IMAGE Crater Diameter (in km)

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	17	124292.20	7311.31	99.47	<.0001
Error	384325	28248733.53	73.50		
Corrected Total	384342	28373025.73			

R-Square	Coeff Var	Root MSE	DIAM_CIRCLE_IMAGE Mean
0.004381	241.0486	8.573342	3.556686

Source	DF	Anova SS	Mean Square	F Value	Pr > F
LATITUDE_GROUP	17	124292.1958	7311.3056	99.47	<.0001

Figure 6: Relationship of crater latitude group (categorical variable) and crater diameter (quantitative variable). Proc ANOVA procedure. Interpret columns F Value and P Value(99.47, 0.0001).

The ANOVA Procedure

Duncan's Multiple Range Test for DIAM_CIRCLE_IMAGE

Note: This test controls the Type I comparisonwise error rate, not the experimentwise error rate.

Alpha	0.05
Error Degrees of Freedom	384325
Error Mean Square	73.5022
Harmonic Mean of Cell Sizes	705.6669

Note: Cell sizes are not equal.

Number of Means	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**
Critical Range	0.895	0.942	0.974	0.997	1.015	1.030	1.043	1.054	1.063	1.071	1.079	1.085	1.091	1.097

16	**17**	**18**
1.102	1.106	1.111

Means with the same letter are not significantly different.					
Duncan Grouping			**Mean**	**N**	**LATITUDE_GROUP**
	A		11.2684	44	8
	B		5.0076	18758	-6
	B				
	B		4.9270	631	-9
	B				
C	B		4.8263	13528	-7
C	B				
C	B	D	4.3694	6983	-8
C	B	D			
C	B	D	4.3176	25392	-5
C		D			
C	E	D	3.8681	34576	-4
	E	D			
F	E	D	3.4729	46156	-2
F	E	D			
F	E	D	3.4511	46503	-3
F	E	D			

Figure 7: Relationship of crater diameter (quantitative variable), crater depth (quantitative variable), and latitude group (categorical variable). Proc ANOVA procedure with Duncan's multiple range test. Interpret column Duncan Grouping. (1 of 2)

The ANOVA Procedure

Duncan's Multiple Range Test for DIAM_CIRCLE_IMAGE

Note: Cell sizes are not equal

Means with the same letter are not significantly different.					
Duncan Grouping			Mean	N	LATITUDE_GROUP
F	E	D	3.3732	32364	0
F	E	D			
F	E	D	3.3559	40922	-1
F	E				
F	E		3.2558	30414	1
F	E				
F	E		3.1461	2780	7
F	E				
F	E		3.1058	28990	2
F	E				
F	E		3.0962	23365	3
F	E				
F	E		3.0014	14162	4
F					
F			2.7450	10800	5
F					
F			2.5939	7975	6

Figure 8: Relationship of crater diameter (quantitative variable), crater depth (quantitative variable), and latitude group (categorical variable). Proc ANOVA procedure with Duncan's multiple range test. Interpret column Duncan Grouping. (2 of 2)

The FREQ Procedure

Table of PRIMARY_MORPHOLOGY by HEMISPHERE				
		HEMISPHERE(Hemisphere with respect to equator (0=South, 1=North))		
		0	1	Total
PRIMARY_MORPHOLOGY(Crater has a classifiable primary morphology (1) or does not (0))				
0	Frequency	207584	132134	339718
	Percent	54.01	34.38	88.39
	Row Pct	61.10	38.90	
	Col Pct	88.92	87.57	
1	Frequency	25865	18760	44625
	Percent	6.73	4.88	11.61
	Row Pct	57.96	42.04	
	Col Pct	11.08	12.43	
Total	Frequency	233449	150894	384343
	Percent	60.74	39.26	100.00

Statistics for Table of PRIMARY_MORPHOLOGY by HEMISPHERE

Statistic	DF	Value	Prob
Chi-Square	1	163.5012	<.0001
Likelihood Ratio Chi-Square	1	162.4070	<.0001
Continuity Adj. Chi-Square	1	163.3693	<.0001
Mantel-Haenszel Chi-Square	1	163.5007	<.0001
Phi Coefficient		0.0206	
Contingency Coefficient		0.0206	
Cramer's V		0.0206	

Fisher's Exact Test	
Cell (1,1) Frequency (F)	207584
Left-sided Pr <= F	1.0000
Right-sided Pr >= F	1.794E-37
Table Probability (P)	2.516E-38
Two-sided Pr <= P	3.441E-37

Sample Size = 384343

Figure 9: Relationship of crater diameter (quantitative variable), crater depth (quantitative variable), and latitude group (categorical variable). Proc ANOVA procedure with Duncan's multiple range test. Interpret column Duncan Grouping. (2 of 2)