



UNIVERSIDADE ESTADUAL DE CAMPINAS
Instituto de Geociências

Caio Vidaurre Nassif Villaça

Análise morfométrica das crateras de impacto de Plutão

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**UNIVERSIDADE ESTADUAL DE CAMPINAS
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SÚMULA/BIOGRAFIA

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RESUMO

Os dados referentes à morfometria de crateras de impacto são fundamentais para o entendimento da evolução do Sistema Solar e dos corpos que o compõem. Em julho de 2015, a sonda *New Horizons* imageou aproximadamente 35% da superfície de Plutão. Desde então, alguns estudos preliminares referentes à morfometria das suas crateras de impacto foram realizados, sendo que o tema necessita ainda ser mais aprofundado. O escopo deste trabalho é realizar uma análise detalhada da morfometria das crateras de impacto de Plutão, utilizando imagens da missão *New Horizons* cujas resoluções variam entre 80 e 400 m/px. Foi utilizado um MDE (Modelo Digital de Elevação) global de Plutão com resolução de 300 m/px, criado a partir de pares estereoscópicos, para extrair os dados morfométricos das estruturas de impacto. A superfície de Plutão foi dividida em cinco regiões de acordo com as características morfométricas das crateras, a fim de analisar possíveis diferenças na dinâmica de impacto e taxa de erosão em cada região. Para isso, foram obtidos dados referentes a profundidade das crateras, diâmetro, inclinação da parede interna, desvio padrão da profundidade, diâmetro da base da cratera e espessura das paredes. Com a análise dos dados, concluímos que as crateras de um mesmo diâmetro localizadas acima de 30°N são relativamente mais rasas do que as crateras equatoriais. Este fenômeno pode estar relacionado à maior presença de voláteis próximo ao polo norte. Com isso, propomos duas hipóteses: 1) A presença de voláteis pode afetar a formação das crateras ao tornar a superfície impactada mais fraca e suscetível a maiores modificações (e.g. deslizamento de massa e colapso das paredes) durante o processo de formação, até alcançar o estágio final de estabilização da cratera. 2) A maior concentração de voláteis em determinadas áreas pode afetar a profundidade das crateras por meio de decantação atmosférica, uma vez que esses elementos possuem ciclos de decantação e sublimação que variam segundo as estações do ano de Plutão. O diâmetro de transição entre crateras simples e complexas é distinto para diferentes áreas de estudo. As crateras nas áreas 1 e 4 exibem um diâmetro de transição (D_t) de aproximadamente 10 km, enquanto o D_t para as crateras nas áreas 3 e 5 ocorre em aproximadamente 15 km. Essa diferença do D_t em diferentes regiões pode estar relacionado a diferentes proporções entre rocha e gelo na superfície do planeta anão.

Palavras-chave: Crateras de impacto; Plutão; Morfometria

Abstract

Morphometry data of impact craters are fundamental for understanding the evolution of the Solar System and its planetary component bodies. In July 2015, the *New Horizons* probe imaged approximately 35% of Pluto's surface. Since then, some preliminary studies regarding the morphometry of its impact craters have been carried out, although the subject needs to be further investigated. The scope of this work is to carry out a detailed analysis of the morphometry of Pluto's impact craters, using images from the New Horizons mission with resolutions varying between 80 and 400 m/px. A global Pluto DEM (Digital Elevation Model) with a resolution of 300 m/px, created from stereoscopic pairs, was used to extract the morphometric data of impact craters. Pluto's surface was divided according to crater morphometric characteristics to analyze possible differences in impact dynamics and erosion rates in each region. Data were obtained regarding the depth of the craters, diameter, inclination of the inner wall, standard deviation of depth, diameter of the base of the crater and thickness of the walls. Based on data analysis we conclude that craters of same diameter above 30°N are shallower than their equatorial equivalents. This phenomenon may be related to the presence of more volatiles near the north pole. We propose two hypotheses: 1) The presence of volatiles can affect the formation of craters by making the impacted surface weaker and susceptible to major changes (e.g., mass sliding and collapse of the walls) during the crater formation process, until they reach stabilization. 2) The higher concentration of volatiles can affect the depth of the craters by means of atmospheric decantation, considering that these elements have decantation and sublimation cycles that vary according to Pluto's different seasons. The transition diameter from simple to complex crater was found to change throughout the areas of study. Craters within areas 1 and 4 exhibit a transition diameter (D_t) of approximately 10 km, while D_t for craters within areas 3 and 5 occurs at 15 km, approximately. This difference in D_t in different regions may be related to different proportions between rocky material and ice on the surface of the dwarf planet.

Keywords: Impact crater; Pluto; Morphometry

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1. Introdução

A formação de crateras de impacto é um dos processos geológicos mais fundamentais do Sistema Solar, tendo em vista que é um fenômeno que vem atuando desde a acreção de corpos no disco protoplanetário, durante a fase inicial do Sistema Solar até os dias de hoje. Trata-se, portanto, de processo por meio do qual as superfícies planetárias evoluem e são modificadas. Os dados de mapeamento e estudo morfométrico de crateras de impacto podem ser utilizados para a datação relativa das superfícies de corpos planetários e para a elaboração de modelos de composição da subsuperfície (Singer et al., 2016; Schenck, 2002). Pode-se também utilizar as informações obtidas a partir das crateras de impacto para estudar, indiretamente, a população dos possíveis projéteis a partir da lei de escala revisada por Holsapple et al. (1993), que calcula o tamanho dos projéteis com base no diâmetro das crateras de impacto.

O processo de formação de crateras de impacto ocorre em três estágios: (1) estágio de contato e compressão, (2) estágio de escavação, e (3) estágio de alteração (French, 1998) (Fig. 1). O estágio de contato e compressão é aquele que compreende a fase de contato do bólido (projétil) com a superfície do alvo, transmitindo a energia cinética do projétil para a subsuperfície do corpo atingido na forma de ondas de choque. O estágio de escavação compreende o processo da formação da cavidade e ejeção de material composto por fragmentos do alvo e do bólido, formando a cratera transiente. Este material ejetado pode ser depositado na parte externa e interna da cratera, que posteriormente formará as brechas de impacto do tipo alóctone. Por último, o estágio de modificação que compreende todo o processo de preenchimento da cratera pelo deslizamento de material de suas paredes e deposição do material ejetado, formando a cratera final. French (1998) também explica que a cratera final, dependendo de suas características morfológicas, pode ser definida como uma cratera simples ou complexa. As crateras complexas possuem maior diâmetro do que as crateras simples formadas em um mesmo corpo celeste, e a sua característica morfológica clássica é a presença de um pico central formado pelo soerguimento de uma porção da base da cratera.

Robbins et al. (2018) comentam sobre o fato de que, durante a formação de uma cratera complexa, mais material é colapsado em direção ao interior da cratera, formando uma base mais plana quando comparada com as crateras simples. Já as crateras simples, segundo Robbins et al. (2018), possuem forma curvilínea mais pronunciada em comparação com as crateras complexas. Existe, portanto, para cada corpo do Sistema Solar, um diâmetro de transição (D_t), que delimita a formação de crateras simples (formadas abaixo de D_t) e de crateras complexas (formadas acima do D_t). Essa transição entre cratera simples e complexa ocorre devido à mudança do fator que predomina no processo de formação das crateras. Na formação das crateras simples, o fator predominante é a resistência do alvo, já que a sua reologia é suficiente para sustentar a formação da cratera transiente (Melosh, 1989). Já para as crateras complexas, a cratera transiente não é mais sustentada somente pela reologia do alvo, precisando, assim, tomar uma forma mais estável para a redistribuição de massa; Neste caso, o regime dominado pelo fator gravidade do corpo-alvo predomina neste cenário (O'Keefe e Ahrens, 1993).

Os principais fatores que influenciam na formação de crateras são: gravidade do corpo planetário atingido e sua composição (Melosh, 1989; O'Keefe e Ahrens, 1993; French, 1998), além de composição, velocidade e ângulo do projétil (French, 1998). Projéteis com velocidades próximas a 2 km/s (velocidade de impacto prevista para Plutão) geram razões p/D (p = profundidade; D = diâmetro) maiores do que crateras que foram formadas por projéteis mais velozes (Bray e Schenk, 2015). Além desses fatores, o ângulo de impacto também influencia na morfologia e no volume da cratera. Impactos com ângulos menores que 90° (considerados ortogonais à superfície) e maiores que 30° podem deformar a cratera final nos seguintes aspectos: (i) a borda ficará mais alta no sentido do impacto; (ii) pode haver deslocamento do pico central (geralmente presente no centro da cratera); (iii) o material ejetado é distribuído, em sua grande parte, de acordo com o sentido do impacto; e (iv) o volume da cavidade diminui em crateras formadas por ângulos oblíquos; porém, somente em ângulos abaixo de 30° as crateras deixam de ser circulares e passam a ser elípticas. Com isso, somente 2 a 4% das crateras tendem a ser elípticas (Elbeshausen e Wünnemann, 2011; Grey et al., 2002; Collins et al., 2011).

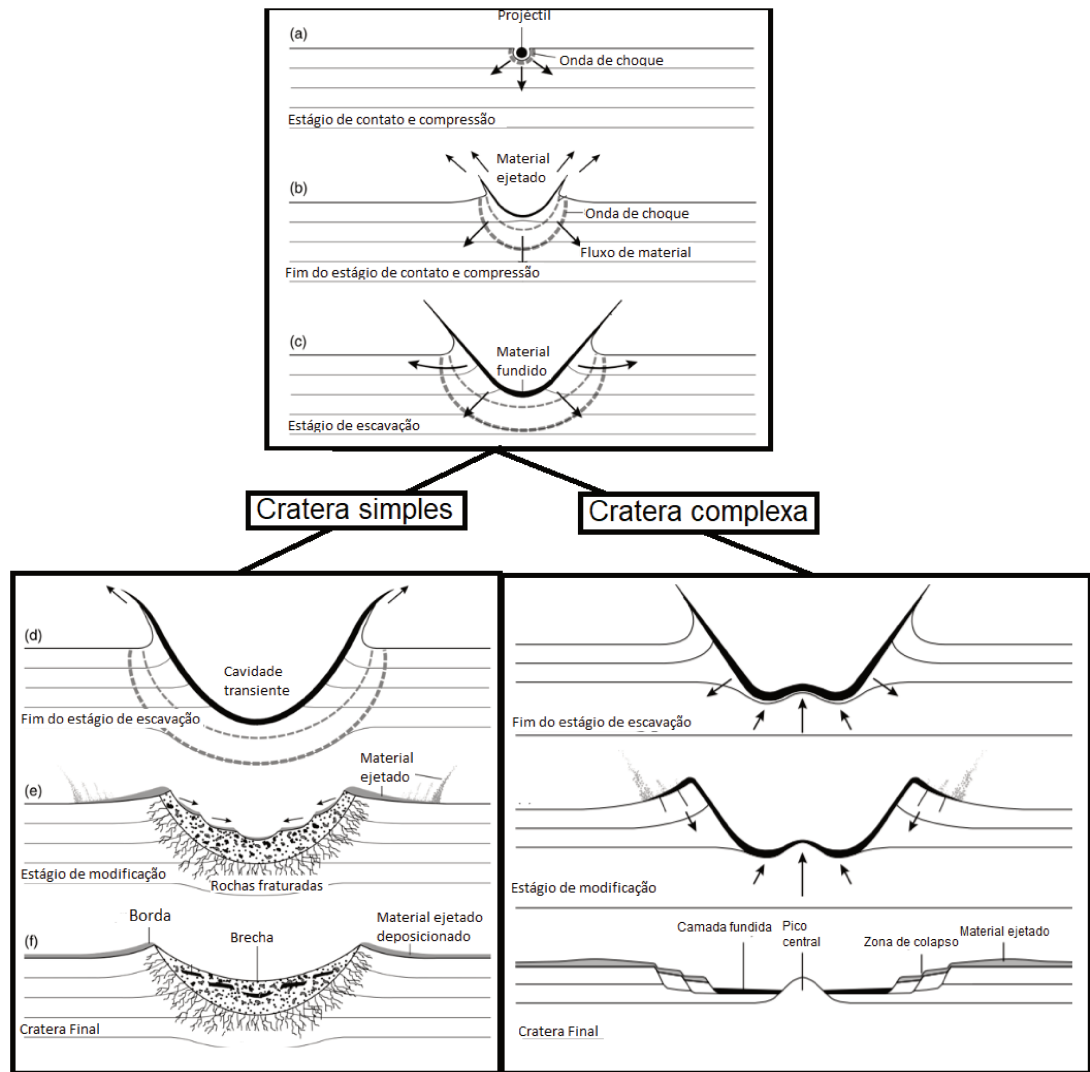


Figura 1. As três principais etapas da formação de crateras simples e complexa (Modificado de French, 1998).

Muitos autores procuram estabelecer uma relação entre morfometria e diferenças reológicas na crosta do corpo-alvo. Robbins e Hynek (2012) estudaram a morfometria de crateras de impacto maiores do que 3 km de diâmetro em diferentes litologias da superfície marciana. Esses autores encontraram que, para crateras que se formaram em rocha mais resistente (rochas vulcânicas próximas ao equador), o diâmetro de transição é menor do que para crateras formadas em litologias menos resistentes (regiões polares ricas em voláteis). O trabalho de Watters et al. (2015)

também demonstra que, para crateras bem conservadas e menores do que 1 km de diâmetro em Marte, além das estruturas em rochas sedimentares erodirem mais rapidamente, a profundidade é maior se formada em rochas mais resistentes. Uma das grandes dificuldades ressaltadas em ambos os trabalhos, é que o conhecimento atual sobre a geologia de corpos extraterrestres é somente superficial, o que pode prejudicar a associação da morfometria medida a partir de técnicas de geoprocessamento com a reologia da subsuperfície de corpo em estudo.

Em julho de 2015, a sonda *New Horizons*, portando os sensores *Multicolor Visible Imaging Camera* (MVIC) e *Long Range Reconnaissance Imager* (LORRI), alcançou o sistema binário Plutão-Charonte e gerou imagens de alta resolução (variando entre 80 e 400 m/px). Com a chegada da *New Horizons* a Plutão, proporcionando a observação desse planeta anão com detalhes até então inéditos, a complexidade geológica do mesmo ficou evidente. As imagens indicam que Plutão possui regiões que variam de relevos muito montanhosos (montanhas de gelo) a muito planos (*Sputnik Planitia*), além de atividade tectônica nos terrenos compostos por gelo, com atividades relativamente recentes (~10Ma) (Moore et al., 2016). Stern et al. (2015) descrevem a superfície de Plutão como sendo composta por gelos de H₂O, CH₄, CO e N₂, e cada um desses compostos apresenta reologia distinta. Moore et al. (2016) elaboraram um mapa geológico preliminar de Plutão, delimitando os principais domínios geomorfológicos e feições de sua superfície. Com esse mapa, já é possível identificar possíveis diferenças composicionais na superfície de Plutão, como é o caso das montanhas de gelo a oeste de *Sputnik Planitia*, que possuem um declive de 30°, ângulo que somente gelo de H₂O (mais resistente) suportaria. Hammond et al. (2016) estudaram fissuras com aproximadamente 4 km de profundidade na superfície de Plutão e concluíram que essas feições poderiam ser causadas por uma tectônica extensional, resultante da expansão de Plutão, que provavelmente se deve ao congelamento de um suposto oceano subsuperficial à crosta de gelo.

Desde a chegada da sonda *New Horizons* a Plutão, pode-se destacar os trabalhos de Moore et al. (2016) e Robbins et al. (2017) sobre as crateras de impacto em Plutão. Moore et al. (2016) descreveram de maneira geral a superfície de Plutão, identificando os seus principais domínios morfológicos e estruturas geológicas. Robbins

et al. (2017) elaboraram um banco de dados com as estruturas circulares na superfície de Plutão, identificando aproximadamente 5.200 possíveis crateras de impacto meteorítico. Além disso, Robbins et al. (2017) calcularam também a frequência de impactos em relação ao tamanho das crateras de Plutão e concluíram que o planeta anão possui uma grande heterogeneidade no que se diz respeito à distribuição de crateras pela superfície, o que se reflete em idades distintas para a sua superfície.

Sabe-se também que a velocidade média de impacto em Plutão é de 2 km/s (Zahnle et al., 2003), considerada uma baixa velocidade. Portanto, espera-se que Plutão apresente crateras mais profundas do que outros corpos atingidos por projéteis com velocidades mais altas (Bray e Schenk, 2015). Nenhuma cratera secundária (cratera formada a partir do material ejetado durante a formação de uma cratera primária) foi ainda identificada em Plutão (Bierhaus et al., 2018), o que pode ser fruto da resolução espacial relativamente baixa das imagens disponíveis de Plutão, ou então da ausência de pesquisa que busquem especificamente esse tipo de feição.

Tendo em vista a relativa ausência desse tema na literatura, a complexidade geológica e a possibilidade de estudar indiretamente os objetos do cinturão de Kuiper, escolhemos Plutão como objeto de estudo para o desenvolvimento deste trabalho. O intuito é contribuir para o entendimento da dinâmica de impacto e modificação das crateras em diferentes terrenos do planeta anão. Neste trabalho apresentaremos as discussões oriundas da análise mais detalhada referente à morfometria das crateras de impacto de Plutão. Esta dissertação foi estruturada com base em manuscrito de artigo científico (Anexo), que aborda de maneira detalhada os métodos, resultados e discussões obtidas a partir dos dados coletados. As discussões se baseiam em dados obtidos a partir da análise morfométrica de 237 crateras de impacto. A seguir será apresentada uma revisão bibliográfica sobre o tema, assim como uma síntese dos resultados obtidos neste trabalho.

2. Estado da arte

Uma revisão bibliográfica mais aprofundada foi realizada para estabelecer o estado da arte da pesquisa sobre a morfometria das crateras de impacto no Sistema Solar e, em particular, em Plutão.

Robbins et al. (2018) revisaram os principais métodos de análise morfométrica de crateras de impacto usando sensoriamento remoto. Os autores destacam dois métodos para coletar dados morfométricos de crateras de impacto: análise de terreno usando modelos digitais de elevação (MDEs) e análise de comprimento de sombra. A preferência pelo uso dos MDEs é enfatizada para a obtenção dos dados morfométricos, pois permite a análise das estruturas em três dimensões. Apesar das limitações da análise do comprimento da sombra, esse método pode ser usado como um complemento na coleta de dados. No caso da análise em três dimensões através do MDE, existem alguns métodos que seguem princípios diferentes para definir a profundidade das crateras. Os métodos discutidos por Robbins et al. (2017) são: elevação máxima/elevação mínima; média da elevação máxima/média da elevação mínima (ou elevação mínima); medida da elevação do terreno ao redor da cratera/elevação mínima do interior da cratera.

Diversas técnicas já foram usadas para delinear e medir crateras de impacto: manualmente, semiautomática ou automaticamente. Talpe (2012) definiu a borda das crateras de impacto usando apenas os dois pontos mais altos de um perfil. Geiger (2013) automatizou o delineamento de crateras de impacto em Marte usando um software em linguagem Python. O software criado por eles analisa, para a mesma cratera, vários perfis, em várias direções, em busca de três pontos de referência: ponto de quebra de declividade (QD), ponto de máxima elevação (EM) e ponto de máxima elevação local (ML). A partir de um ponto inicial, o software procura um ponto QD no próximo perfil. Se não o encontrar dentro de um raio estipulado, o software procurará um ponto EM. No último caso, ele procura o ponto ML. Scholkmann (2016) identificou e mediu manualmente o diâmetro das crateras de impacto a partir das imagens obtidas durante a missão *New Horizons* na superfície de Plutão. Zhou et al. (2018) usaram o

mapa de gradiente de aspecto para delinear as crateras de maneira semi-automática. Este método consiste em destacar o ponto de inflexão máxima, ou a maior alteração na inclinação do aspecto, que corresponderia à borda da cratera (divisão entre a parede interna e a externa). Robbins e Hynek (2012) analisaram a morfometria das crateras de impacto de Marte para determinar o diâmetro de transição global e regional do planeta. Para determinar o diâmetro de transição, esses autores usaram três métodos diferentes: (i) forma da base (bacia ou plana); (ii) identificação do pico central e terraços nas paredes; e (iii) correlação p/D . O diâmetro de transição foi calculado global e territorialmente, levando em consideração três grupos: todas as crateras, as mais profundas e as mais bem preservadas. Esses autores estudaram somente as crateras mais bem preservadas e encontraram grandes diferenças na morfologia de crateras presentes no equador, em relação às crateras próximas aos polos. Neste trabalho, os autores encontraram que crateras simples próximas ao equador possuem uma lei de potência (relação entre duas variáveis que pode ser descrita na fórmula: $y=ax^k$, sendo “a” e “k” constantes) entre profundidade e diâmetro de $p = 0.078D^{1.106}$ e as complexas $p = 0.155D^{0.464}$. Já as crateras próximas aos polos possuem uma lei de potência de $p = 0.0028D^{1.843}$ para crateras simples e $p = 0.014D^{1.161}$ para crateras complexas. Com isso, eles concluíram que, para crateras que se formaram em rochas mais resistentes (rochas vulcânicas próximas do equador), o diâmetro de transição é menor do que para crateras formadas em litologia menos resistentes (regiões polares ricas em voláteis). Concluíram ainda que as crateras próximas ao equador são mais profundas do que as próximas aos polos. Ainda segundo Robbins e Hynek (2012), a análise dos dados separados em três grupos foi fundamental para determinar as reais diferenças de morfometria entre regiões. Caso contrário, no caso de Marte, as crateras próximas aos polos sempre pareceriam mais degradadas em comparação às crateras equatoriais. Robbins e Hynek (2012) encontraram diferentes diâmetros de transição para diferentes latitudes: 11 km para regiões polares e 6 km para a média global.

Watters et al. (2015) analisaram a morfometria de crateras de impacto simples (<1 km de diâmetro) na superfície de Marte, a fim de determinar se haveria alguma diferença entre as crateras localizadas em diferentes terrenos litológicos. Eles usaram imagens de alta resolução (1 m/pixel) para criar o MDE e a metodologia de

Geiger (2013) para delinear as crateras de impacto. Os autores analisaram as seguintes características morfométricas para chegar às conclusões do estudo: diâmetro (D), profundidade (p), altura da aresta (h), forma da base, volume da cratera, arredondamento da borda e inclinação da parede. Verificou-se que, com níveis crescentes de modificação, a forma da base se torna mais parabólica / superparabólica e a inclinação das paredes diminui. Além disso, a borda das crateras de impacto se torna mais desgastada com uma modificação crescente, devido ao movimento de massa. A relação p/D diminui com o aumento do nível de deformação das crateras e a relação h/D não mostrou diferença significativa. As crateras que se formaram em regiões de reologia mais resistente (por exemplo, basalto) são mais profundas do que as crateras formadas em material menos resistentes (por exemplo, depósitos de ejeção). Por outro lado, crateras em terrenos contendo gelo (polos marcianos) apresentaram componentes morfométricos semelhantes às crateras em regiões de reologia mais resistente. Portanto, os referidos autores concluem que, para crateras pequenas (<1 km de diâmetro), a reologia não interfere necessariamente na morfologia da estrutura, mas sim na taxa de erosão e modificação desta com o tempo.

Vivaldi (2017) analisou a morfometria das crateras da Lua, quantificando a taxa de erosão e classificando-as de acordo com o nível de preservação. Nesse caso, foi possível quantificar a taxa de erosão devido à presença, na superfície lunar, de uma cratera simples relativamente nova e em excelentes condições. Usando como referência uma cratera em boas condições e conhecendo a idade do terreno, é possível calcular o quanto outra estrutura de impacto foi degradada ao longo do tempo. O cálculo, neste caso, é possível entre crateras simples de tamanhos semelhantes e em regiões de composição geológica parecidas. Para comparação, Vivaldi (2017) analisou os seguintes dados morfométricos: inclinação da parede interna (inversamente proporcional ao grau de deformação), arredondamento da borda da cratera (aumenta com o grau de deformação) e curvatura da base (diminui com o aumento do grau de deformação).

Schenk (2002) estudou a morfometria de crateras de impacto nas superfícies geladas dos satélites Galileanos de Júpiter (Calisto, Europa e Ganimedes) usando a relação p/D , e encontrou três pontos de transição, sendo dois considerados anômalos.

Esse autor interpreta que o primeiro ponto de transição está relacionado à transição da morfologia das crateras simples para complexa, o segundo é referente a uma anomalia da morfometria de crateras complexas, e o terceiro ponto de transição está ligado à uma anomalia na redução da profundidade em relação ao diâmetro (quanto maior a cratera mais rasa ela é). Esse autor, portanto, associou essas anomalias das crateras dos satélites Galileanos a possíveis diferenças na composição e espessura das crostas destes satélites.

Silber e Johnson(2017), utilizando os dados morfométricos das crateras de impacto (principalmente diâmetro e profundidade), compararam os resultados de diferentes modelos de impacto computacional na crosta de Europa. Com isso, os autores puderam determinar a espessura e a composição que melhor se ajustam aos dados morfométricos obtidos por Schenk (2002). Os resultados de Silber e Johnson (2017) apontaram três modelos prováveis para a crosta de Europa, que provavelmente recobre um oceano subterrâneo: (i) uma crosta de 5 km de espessura e com uma camada de gelo condutor sobre uma camada de gelo a 255 K; (ii) uma crosta de 6 a 7 km de espessura com uma camada de gelo condutor cobrindo outra camada de gelo a 265K; e (iii) uma crosta de 8 km de espessura completamente formada por gelo condutor.

Bray e Schenk (2015), com base no conhecimento pré-existente da composição da superfície de Plutão e nos objetos de Kuiper, modelaram como seria a morfometria de uma cratera ideal em Plutão. Para realizar a modelagem, os autores utilizaram a velocidade de impacto prevista por Zahnle et al. (2003) de 2 km/s para os corpos de Kuiper impactando Plutão. Bray e Schenk(2015) observaram que a relação p/D aumentou quando a velocidade de impacto diminuiu de 10 km/s para 2 km/s. Por outro lado, essa relação diminuiu ao comparar velocidades que variam entre 2 km/s e 300 m/s. Essa complexa relação de velocidade de impacto e razão p/D pode significar que Plutão possui uma grande variedade morfométricas relacionada a crateras recém-formadas e bem preservadas, o que dificulta a quantificação da taxa de modificação das estruturas. Segundo as conclusões de Bray e Schenk (2015), dificilmente saberíamos se a variação na morfometria é devida a uma diferença na velocidade de

impacto ou na taxa de erosão. A análise da taxa de modificação, portanto, deve ser feita qualitativamente no caso de Plutão.

Singer et al. (2019), a partir da contagem das crateras de impacto e da análise de seus respectivos diâmetros, determinou a frequência por tamanho das crateras de impacto de Plutão. Assim, os autores observaram um déficit de pequenas crateras (menos de 15 km de diâmetro) em toda a superfície do planeta anão. Como seria improvável que nenhum dos possíveis processos de erosão e modificação presentes em corpos gelados (relaxamento viscoso, atividade tectônica, movimento de massa, erosão glacial pelo fluxo de gelo volátil - N_2 , CO , CH_4 , precipitação de partículas da atmosfera, erosão por sublimação, atividade de convecção de subsuperfície, criovulcanismo) poderia modificar apenas pequenas crateras, Singer et al. (2019) concluíram que deveria existir um déficit de pequenos objetos no cinturão de Kuiper.

Robbins et al. (2017) criaram um banco de dados de todas as estruturas circulares na superfície de Plutão, contendo aproximadamente 5.200 estruturas contadas como prováveis crateras. Os autores dividiram as 5.200 crateras em classes de 1 a 5, nas quais as estruturas com baixa confiança recebem o valor 1 e as estruturas com alta probabilidade de serem crateras de impacto recebem o valor 5. Eles observaram que era mais difícil reconhecer crateras em terrenos caóticos (terrenos com alta rugosidade topográfica) em Plutão, onde crateras vulcânicas ou depressões circulares podem ser confundidas com crateras de impacto.

Robbins et al. (2018) , usando a extrapolação da inversão proporcional da gravidade, concluíram que o diâmetro de transição entre crateras simples e crateras complexas deve ser de 4,3 km. Já Schenk et al. (2016), usando a lei de potência com alguns dados preliminares sobre a morfometria das crateras de Plutão, concluíram que o diâmetro de transição entre crateras simples e complexas deve ser 10 km, mesmo valor encontrado por Robbins et al. (2020) a partir da coleta dos valores de diâmetro e profundidade das crateras de impacto.

3. Objetivos

O escopo deste trabalho é determinar a morfometria detalhada das crateras de impacto em diferentes terrenos da superfície de Plutão. Com isso pretende-se avaliar se a dinâmica de impacto se comporta de maneira diferente em cada região da crosta de Plutão e se a taxa de modificação das estruturas se altera de acordo com as diferentes regiões de composições distintas.

4. Materiais e Métodos

A área de estudo compreende a região a oeste de *Sputnik Planitia* entre 0°E e 180°E, onde se encontram as imagens com melhor resolução e maiores densidades de crateras de impacto em uma variedade maior de terrenos morfológicamente distintos. Foi utilizado um MDE (Modelo Digital de Elevação) global de Plutão com resolução de 300 m/px, criado a partir de pares estereoscópicos (Moore et al., 2016), para extrair os dados morfométricos das estruturas de impacto. A extração dos dados morfométricos foi feita de forma semi-automática com o auxílio de um código em Python, elaborado como parte deste projeto. Foram obtidos dados referentes à profundidade das crateras, diâmetro, inclinação da parede interna, desvio padrão da profundidade, diâmetro da base da cratera e espessura das paredes (Figura 2). Com a análise de profundidade e diâmetro das crateras de impacto, a superfície de Plutão foi dividida de acordo com as características morfométricas das crateras, a fim de analisar possíveis diferenças na dinâmica de impacto e na taxa de erosão em cada região.

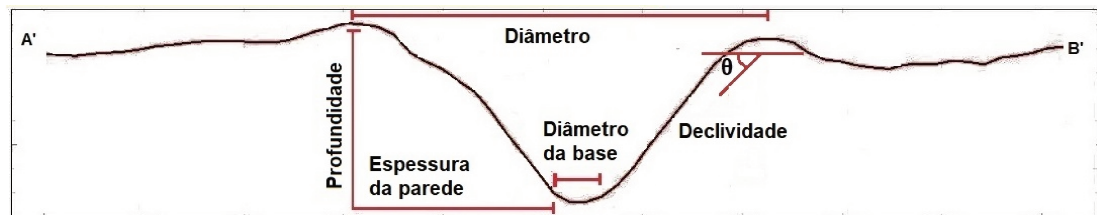


Figura 2: Feições morfométricas coletadas para cada cratera de impacto.

Neste trabalho usamos um método para delinear as crateras de impacto semelhante ao usado por Geiger (2013). A principal diferença entre os dois métodos é que Geiger (2013) usa como principal forma de encontrar a borda da cratera o ponto de quebra do declive. Contudo, com a caótica superfície de Plutão, o método utilizado por Geiger (2013), para delimitar a borda das crateras, criou mais erros.

Para o processamento do código (Fig. 3), dois arquivos raster globais (MDE e mapa de inclinação) são necessários. Em primeiro lugar, o usuário deve identificar a cratera para fins de análise. Com isso, ele irá apenas criar um polígono circular que envolva aproximadamente a cratera. A partir do ponto central do polígono, o código cria automaticamente as linhas de perfil e obtém os valores de inclinação e altura em cada

pixel. O programa então cria dois arquivos: elevação máxima (EM) e ponto de controle (PC).

Os pontos EM são então selecionados a partir do pixel com o maior valor Z (altitude) em cada perfil. Os pontos EM (pixel com maior valor Z de altitude de cada perfil) são selecionados dentro de um raio equivalente a $1 / (4,5)$ do raio do polígono gerado pelo usuário, calculado a partir de sua borda. Essa última etapa é importante para eliminar pontos próximos ao centro das crateras e também integrar uma área além do polígono do usuário. O PC, por outro lado, é o arquivo que contém todos os pixels de cada perfil.

A partir do ponto de partida do EM, o código , procura no próximo perfil (sentido horário) outro ponto EM que esteja dentro de um raio estipulado pelo usuário (usamos 1.000 metros neste trabalho, já que foi o valor que obteve melhores respostas). Os pontos a serem buscados no próximo perfil seguem a ordem de prioridade de: EM > PC. Se o código não encontrar o ponto de prioridade mais alta (EM), ele procura o ponto de prioridade mais baixa (PC) que está mais próximo do ponto EM. O código termina de delinear a cratera assim que todos os perfis forem analisados.

Após delinear as bordas da cratera de impacto, o código extrai os valores morfométricos. A média do diâmetro é calculada, uma vez que a linha de delineamento não é um círculo perfeito, a partir do valor de cada perfil que se estende do centróide até as bordas da cratera. A profundidade da estrutura é calculada por: (ponto de menor cota da base da cratera) - (valor da altura média da parede da cratera), obtendo-se assim um valor absoluto da profundidade em metros. Utilizamos a altura média da parede na medição da profundidade porque parece reduzir a influência da topografia pré-impacto nas análises. Os erros de diâmetro e profundidade foram calculados da mesma maneira que Robbins et al. (2020). O desvio padrão da altura da parede da cratera pode ser usado para auxiliar na interpretação da taxa de modificação das estruturas (crateras bem preservadas devem ter pouca variação na borda) e a influência do terreno nas análises. Para obter o valor médio do declive das paredes internas das crateras, é necessário separar o limite entre a base e a parede interna da estrutura. Caso contrário, a análise será influenciada pela baixa inclinação da base da estrutura. Para este propósito, o código elimina da análise em torno de $\frac{1}{8}$ do raio total

da cratera a partir do centro da mesma. Isso gera um novo polígono, a fim de evitar que as características do pico central interfiram na análise. Em seguida, o código separa a base da cratera da parede interna, calculando $\frac{1}{5}$ do valor total da profundidade de cada perfil calculado no novo polígono. São analisados os valores de altura (Z) dos pixels presentes em cada novo perfil e, caso tenham um valor maior que $\frac{1}{5}$ da profundidade total, são selecionados os pontos que representam o início da parede. Com os pontos selecionados, um novo arquivo é criado que cobre apenas a parede interna da cratera. A partir do arquivo recém-gerado, a inclinação total é calculada em todos os perfis. Na sequência, foi possível separar as crateras consideradas mais preservadas. Para tanto, foram selecionadas apenas as crateras mais profundas para um determinado diâmetro. Além disso, a análise visual também foi conduzida para separar crateras complexas de crateras simples usando principalmente as seguintes características: base plana (complexa) e base parabólica (simples) e presença ou ausência de um pico central.

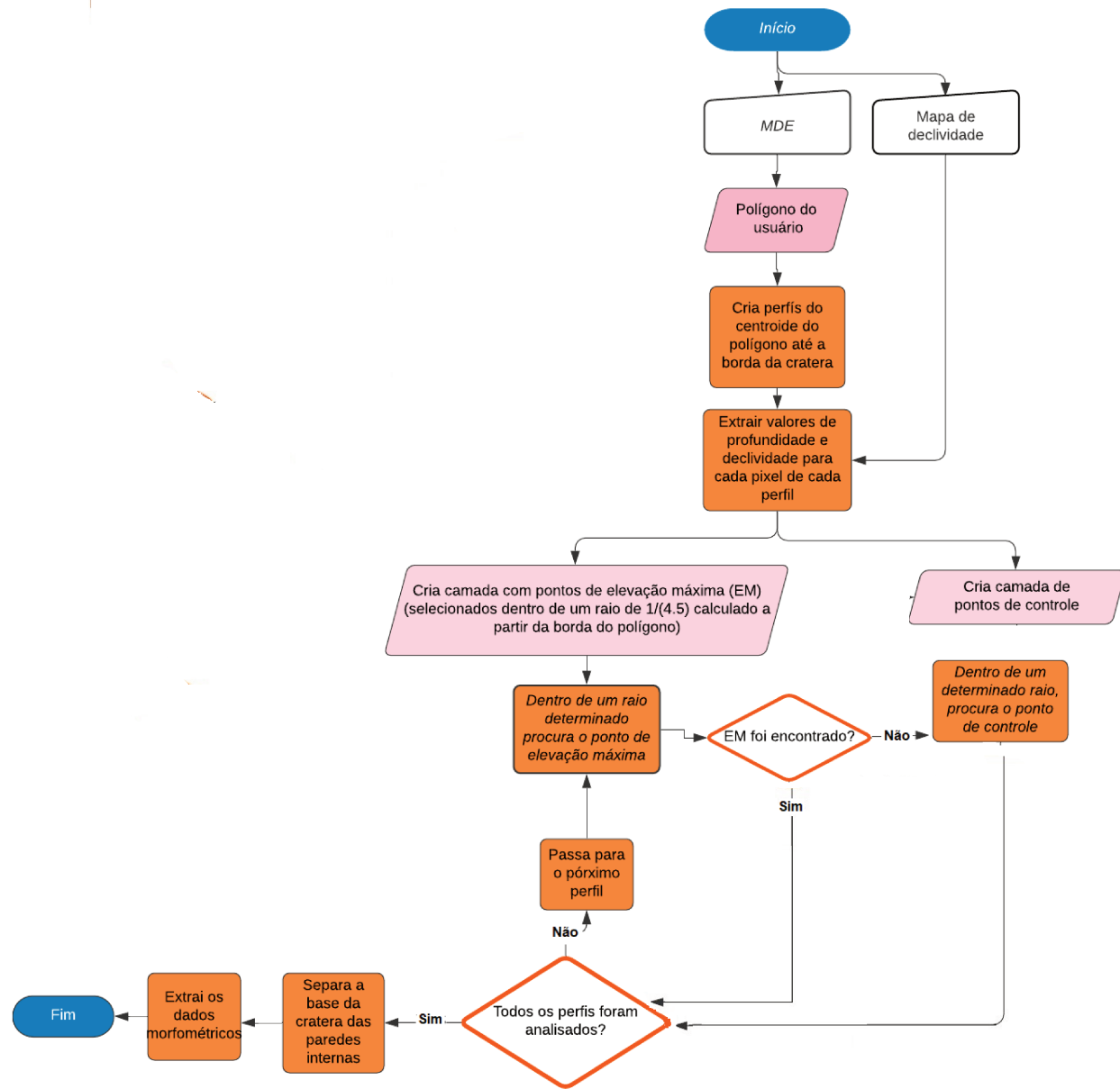


Figura 3: Fluxograma de operação do código Python

5. Síntese dos resultados

Foram coletadas os dados de morfometria (diâmetro, profundidade, declividade das paredes internas, espessura da parede e diâmetro da base da cratera) de 237 crateras de impacto, com tamanhos variando entre 5 e 60 km de diâmetro na região situada a oeste de Sputnik Planitia (área de estudo). A fim de compreender melhor a variabilidade da morfometria das crateras de Plutão, regiões com padrões p/D comuns foram agrupadas em cinco grupos distintos. Foi então observado que as crateras presentes nos grupos mais ao norte-noroeste da área de estudo são mais rasas considerando um determinado diâmetro. Além disso, foram encontrados dois diâmetros de transição, um em aproximadamente 10 km e outro em aproximadamente 15 km.

6. Discussão e Conclusões

Nós relatamos as diferenças de análise das características morfométricas na superfície de Plutão para uma população de crateras distribuída global e localmente. Conduzimos um estudo detalhado da morfometria usando crateras na faixa de 5 a 60 km de diâmetro. Esses resultados fornecem novas percepções sobre as relações entre os parâmetros morfométricos e a composição dos terrenos e, conseqüentemente, sua reologia, oferecendo informações importantes para a modelagem da evolução da superfície de corpos planetários gelados e a formação de crateras, a serem considerados em trabalhos futuros.

A diferença no diâmetro de transição em diferentes áreas da superfície de Plutão, encontrada neste trabalho, pode estar relacionada a diferentes proporções entre rocha e gelo para cada região (Robbins et al., 2020). Também foram relatadas mudanças nas tendências dos gráficos para crateras maiores que 20 km de diâmetro, que podem representar uma mudança no regime de formação de crateras.

De acordo com Grundy et al. (2016), a presença de gelo de N_2 , CO e CH_4 é claramente observada nas áreas do norte de Plutão. Esses compostos são todos voláteis em temperaturas da superfície do planeta anão, de 35 a 50 K, e muitas crateras em regiões ocidentais acima de 0° de latitude mostram feições de absorção de CH_4 em suas bordas. Portanto, outra ideia para explicar as diferenças morfométricas entre as regiões de Plutão é a presença de voláteis durante a formação da cratera (durante sua fase de modificação), onde a energia do impacto ocasiona o preenchimento das crateras pelos materiais voláteis (Robbins e Hynek, 2012). As baixas profundidades nas regiões norte-noroeste também podem ser devidas ao ciclo de sublimação e deposição dos voláteis durante as diferentes estações do ano em Plutão, que podem influenciar na erosão e modificação das crateras de forma mais intensa em comparação com as regiões equatoriais (Grundy et al., 2016).

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Morphometric Analysis of Pluto’s Impact Craters

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Abstract: The scope of this work is to carry out a morphometric analysis of Pluto’s impact craters. A global Pluto digital elevation model (DEM) with a resolution of 300 m/px, created from stereoscopic pairs obtained by the New Horizons Mission, was used to extract the morphometric data of craters. Pluto’s surface was divided according to different morphometric characteristics in order to analyze possible differences in the impact dynamics and modification rate in each region. A Python code was developed, within the QGIS 3x software environment, to automate the process of crater outlining and collection of morphometric data: diameter (D), depth (d), depth variation, slope of the inner wall (Sw), diameter of the base (Db), and the width of the wall (Ww). Data have been successfully obtained for 237 impact craters on five distinct terrains over the west side of Sputnik Planitia on Pluto. With the collected data, it was possible to observe that craters near the equator (areas 3 and 4) are deeper than craters above 35°N (areas 1 and 2). Craters on the western regions (areas 2 and 3) contain the lowest depth values for a given diameter. The transition diameter from simple to complex crater morphology was found to change throughout the areas of study. Craters within areas 1 and 4 exhibit a transition diameter (Dt) of approximately 10 km, while Dt for craters within areas 3 and 5 the transitions occurs at 15 km approximately. The presence of volatile ices in the north and north-west regions may be the reason for the difference of morphometry between these two terrains of Pluto. Two hypotheses are presented to explain these differences: 1) The presence of volatile ices can affect the formation of craters by making the target surface weaker and more susceptible to major changes (e.g., mass waste and collapse of the walls) during the formation process until its final stage; 2) The high concentration of volatiles can affect the depth of the craters by atmospheric decantation, considering that these elements undergo seasonal decantation and sublimation cycles.

Keywords: New Horizons; Pluto; impact crater; morphometry

1. Introduction

Impact cratering is an active and fundamental phenomenon from the initial accretion of bodies on the protoplanetary disk to the present day. It is the main process by which planetary surfaces are modified. Morphometric data of impact craters are fundamental for understanding the evolution of the Solar System and its components [1]. The study of impact craters can result in a vast amount of information, such as the ages, rheology properties, erosion rate of planetary surfaces, as well as constrain the cratering history (impact flux) on terrestrial planets and other solid planetary bodies [2].

Robbins et al. [3] reviewed the main methods for morphometric analysis of impact craters using remote sensing data. Since digital elevation models (DEMs) allow the analysis of these structures in three dimensions, Robbins et al. [3] favor the use of DEMs to obtain morphometric data. Robbins and Hynek [4] analyzed the morphometry of Mars' impact craters in order to determine the planet's global and regional transition diameter (D_t). D_t represents the threshold that defines the formation of simple craters (formed below D_t) and complex craters (formed above D_t). This transition between simple and complex craters occurs due to a change in the regime that predominates in the process of crater formation [5]. Robbins and Hynek [4] found that, near Mars' equatorial region ($D_t = 6$ km), the craters are deeper than those near the poles ($D_t = 11$ km), probably due to the presence of volatile elements. Watters et al. [6] observed that Martian craters that were formed in regions of more resistant rheology (e.g., basalt) are deeper than craters formed in weaker material (e.g., ejecta deposits).

In July 2015, the New Horizons spacecraft imaged approximately 30% of Pluto's surface [7]. Since then, some preliminary studies regarding the morphometry of its impact craters have been carried out, and the subject needs to be further investigated. According to Moore et al. [8], the New Horizons mission found out that Pluto's surface is mainly composed of H_2O , CH_4 , CO , and N_2 ices. The dwarf planet has active geological processes and atmospheric cycles which still modify its surface in the present. Robbins et al. [9] identified approximately 5200 circular structures on Pluto's surface and divided them into a five-point scale system, where one means little chance of being an impact crater and five indicates a certain impact crater. Robbins et al. [9] measured the diameter of each impact crater on Pluto to create a global distribution of impact frequency by size. A preliminary division of Pluto's surface into morphological domains was presented by Moore et al. [8]. Robbins et al. [10] measured the depth and diameter of 113 craters on Pluto's surface and deduced a global transition diameter of approximately 10 km.

Singer et al. [7] observed a deficit of small craters (less than 15 km) over the entire surface of the dwarf planet by analyzing their size frequency distribution (SFD). As it would be unlikely that the possible processes of erosion and modification present in icy bodies could modify only small craters, this observation may also reflect the deficit of small objects in the Kuiper belt. It is still necessary to analyze in more detail the morphometry of Pluto's impact craters in order to help decipher their formation dynamics and the processes that could modify them throughout the dwarf planet's surface.

Since Pluto exhibits a complex geology (Figure 1), the scope of this work is to carry out a detailed analysis of the morphometry of the impact craters larger than 5 km and up to 60 km in diameter, within different terrains across Pluto's surface. This is

intended to assess if there is any correlation between the differences of morphometry and the different compositions of Pluto's surface. In addition, we investigate the transition diameter between simple and complex craters of Pluto in these different terrains.

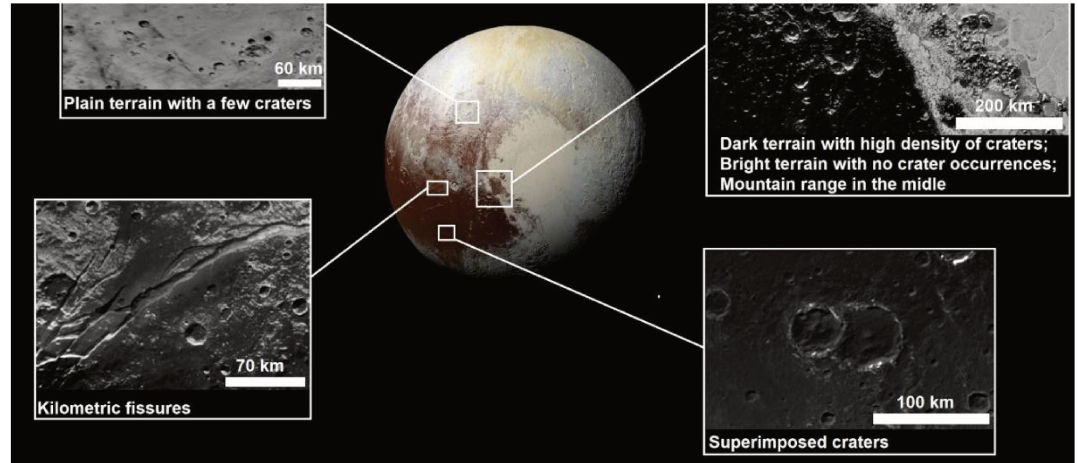


Figure 1. Global view of Pluto obtained by the combination of blue, red and infrared images taken by the Ralph/Multispectral Visual Imaging Camera (MVIC) (Image modified from Moore et al. [8] and Schenk et al. [11]; www.solarsystem.nasa.gov).

2. Materials and Methods

2.1. Study Area

Pluto, currently designated as a dwarf planet, is 5.9 billion kilometers from the Sun and is the main object of the Kuiper Belt. The study area comprises the region west of Sputnik Planitia (SP), between 0° and 180° longitude (Figure 2). In this area, images with the best spatial resolution acquired by New Horizons are found in a variety of morphologically distinct domains containing the majority of impact structures of Pluto's surface [7,9].

Pluto's surface is composed mainly of H_2O , CH_4 , N_2 , and CO ices [8]. H_2O ice is known to be a strong material, capable of forming mountains with high slopes [8]. N_2 , CO , and CH_4 ices are all volatile elements at Pluto's surface temperatures of 35 to 50 K [12]. According to these authors, N_2 is the most volatile ice in the surface of Pluto and is concentrated mostly above 30°N . North-west regions have the presence of bright halo craters, which have a dark base and a high albedo edge, probably composed of methane (CH_4). Pluto has a variety of exogenic and endogenic processes that modify its surface: viscous relaxation, tectonic processes, mass waste, glacial erosion by the flow of volatile ice, precipitation of particles from the atmosphere, erosion by sublimation, subsurface convection activity, and cryovolcanism [7,8,12].

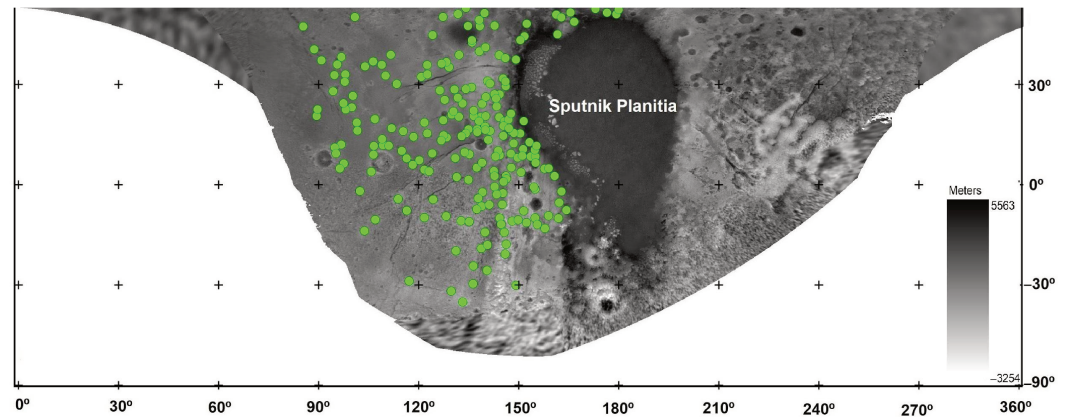


Figure 2. DEM of Pluto's surface [8], [11]. Dots represent the 237 craters analyzed in this work (Table S1).

2.2. Morphometric Analysis

In view of the wide variety of methods for outlining impact craters, this study uses as a basis the method developed by Geiger [13]. A Python code was developed (see supplementary material) in order to automate the outlining step of impact craters and create a systematic method that can be easily replicated. The code works in the QGIS 3x software environment [14]. It was used to outline 237 craters (Table 1S). We have considered successful outlines the ones with minimum visual errors (Figure 3A). The largest errors occurred in very uneven terrains (Figure 3B), where the pre-impact topography influences the analysis. Because the analysis conducted in this work covers the average values for each morphometric feature, small errors should not strongly influence the final results. The code calculates the following morphometric data: diameter (D), depth (d), depth variation, slope of the inner wall (S_w), diameter of the base (D_b), and the width of the wall (W_w) (Figure 3C). It also calculates the standard deviation of each value and extracts the coordinates of each crater.

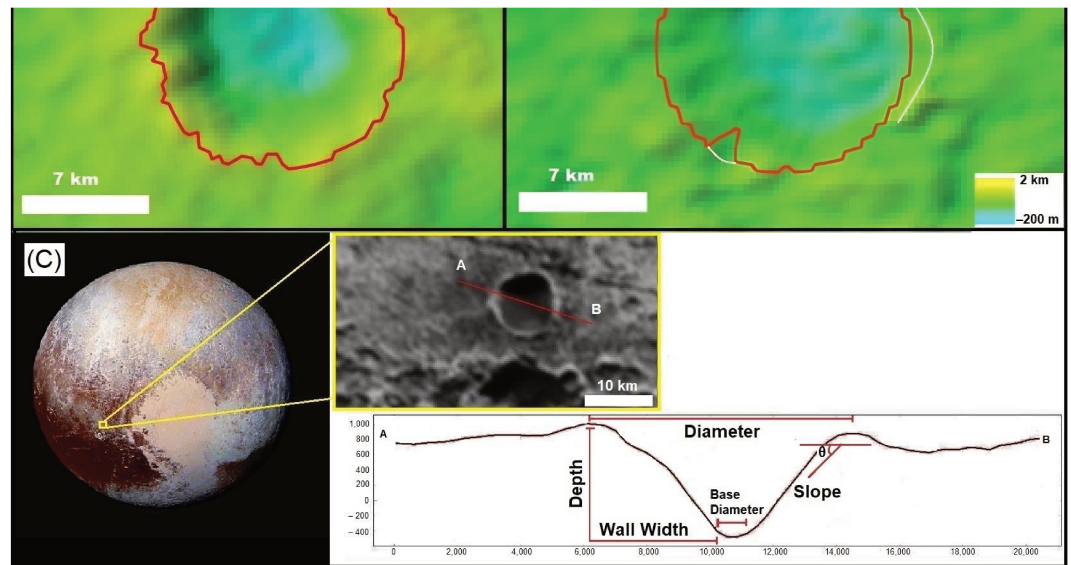


Figure 3. (A) Crater with a good outline. (B) Crater with some outline errors and, therefore, excluded from further analysis. The red lines represent the outlines processed by the Python code for two different craters, each one with different levels of success. White lines represent the ideal outline. (C) Profile of a simple crater on Pluto's surface showing the data extracted by the Python code.

From an initial approximate circle, defined interactively by the user, the code analyses as many profiles as the resolution of the DEM allows. The profiles are 1.3x longer than the fit circle radius in order to increase the chances of the profile encompassing the crater rim. The code first searches for the point of maximum elevation (ME) of an initial profile, then it checks if the ME of the next profile is within a determined radius of the initial ME. If not, a control point in the middle of the first ME and the second ME is selected. The ME points are searched within a determined radius in order to reduce the chances of the code selecting a ME that represents a pre-impact terrain, and not the crater rim. The depth of the structure is calculated by: (point of lowest elevation of the base of the crater) – (value of the average height of the crater wall). More details about the code are explained in the supplementary material.

In order to eliminate projection errors, each crater is reprojected as the center of a stereographic projection, before having their morphometric data extracted by the code. Uncertainties in diameter and depth measurements are calculated according to Robbins et al. [10].

2.3. Modification and Morphologies

According to Bray and Schenk [15], Pluto must have a large spectrum of well-preserved craters with different morphometric features, due to the relative low speed of impacts against its surface. Bray and Schenk [15] show that craters formed by impacts with velocities greater or smaller than 2 km/s are shallower than craters formed by impacts with this velocity. This makes the modification rate analysis qualitative rather than

quantitative, since it is not possible to know if the different morphometry is caused by erosion and modification, or by differences in impact velocity. There are several factors that can modify an impact crater on Pluto: decantation of material suspended in the atmosphere, viscous ice relaxation, tectonics, mass movement, glacial erosion, cryovolcanism, sublimation, filling, and superimposition of craters [7].

In order to remove the influence of anomalous morphometries, as much as possible, craters with an advanced stage of modification were not considered in the analysis. The modification states of the craters analyzed in this work were defined based on two methods: visual analysis of the images and selection of the deepest craters for each region.

The visual analysis of the global panchromatic mosaic of Pluto was complemented with the evaluation of the profiles generated by the algorithm created in this work. We classified, qualitatively, the degree of preservation of the crater shape using the profiles and checking for eventually superimposed craters that could influence the depth of the crater. This analysis can determine whether the craters appear to be modified or not (Figure 4). Craters are considered deformed if the asymmetry between rim high and slope of inner walls are too high, as shown in Figure 4C. In some cases, the superimposed crater modifies the rim, or creates a false notion of increased depth if located inside the crater being analyzed.

The second method to determine the modification rate of craters is the selection of the deepest craters within the same region on Pluto's surface. This method is based on the concept that the deepest craters, within the same rheological material and the same diameter range, are the freshest ones, since they might be the least modified by the main modification processes (infilling or ice relaxation) [4]. Consequently, two datasets are created, one with all craters and the other with only the freshest ones. Craters anomalously deep are removed from the dataset, so it is possible to reduce the chances of factors such as superimposed craters influencing the analysis of the crater's depth. Anomalously deep craters are the ones that exhibit a large depth for its diameter and do not follow the trend of the majority of the craters [3].

The classification of the basic shape of the crater was done manually, observing the profiles extracted by the Python code. Complex craters can be identified by the presence of a central peak, walls containing terraces and a flat base. In the case of filling, the central peak can be buried, so the classification is based mainly on the shape of the base. Simple craters have a more pronounced bowl shape.

The dataset was separated into groups of regions and diameters. This separation is necessary to avoid misinterpretation of the data, since craters in different areas throughout Pluto's surface may contain different primary morphometries, in addition to undergoing different processes of erosion and modification. According to Robbins and Hynek [4], it is important that the deepest crater analysis be separated into regions, since different regions may have fresh craters of the same diameter with different depths due to the composition of the superficial crust. Thus, if the analysis is not done separately for each region, the ones containing shallower craters by nature could always be interpreted as more modified than the others.

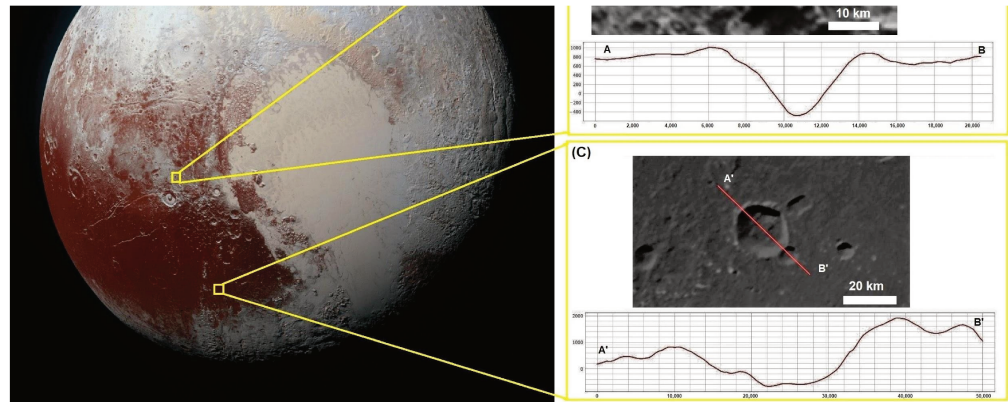


Figure 4: (A) Global view of Pluto. The image combines blue, red and infrared images taken by the Ralph/Multispectral Visual Imaging Camera (MVIC) (Credits: NASA). Profiles x and y axis are in meters. (B) Well preserved simple impact crater. (C) Simple crater with a high level of modification: internal walls with low slope; surrounding craters modify its morphology; rim with uneven height.

3. Results

Figure 5 shows the d/D ratios of the freshest craters versus their location in latitude and longitude. It is noteworthy that the northernmost craters have lower d/D ratios than the others. It is also possible to observe that the southernmost craters do not have depths as shallow as the equatorial and northern craters that reach the lower limit of the d/D ratio. Craters near the equatorial regions show great variability in the data, going from the lowest d/D of 0.04 to the highest d/D ratio value > 0.20 (Figure 5A). In the plot that relates the d/D ratio to the longitude (Figure 5B), we can see that craters located between 150° and 120° have higher d/D ratios than craters to the west ($< 120^\circ$). Western regions exhibit the lowest values of d/D ratios (Figure 5B). Figure 6A shows a heatmap separating the craters in bins of 100 km^2 (bins with no craters are not considered). Figure 6A clearly shows that northwestern areas tend to have lower d/D ratios than southeastern ones, and that craters near the equator have the highest for d/D ratios and variability.

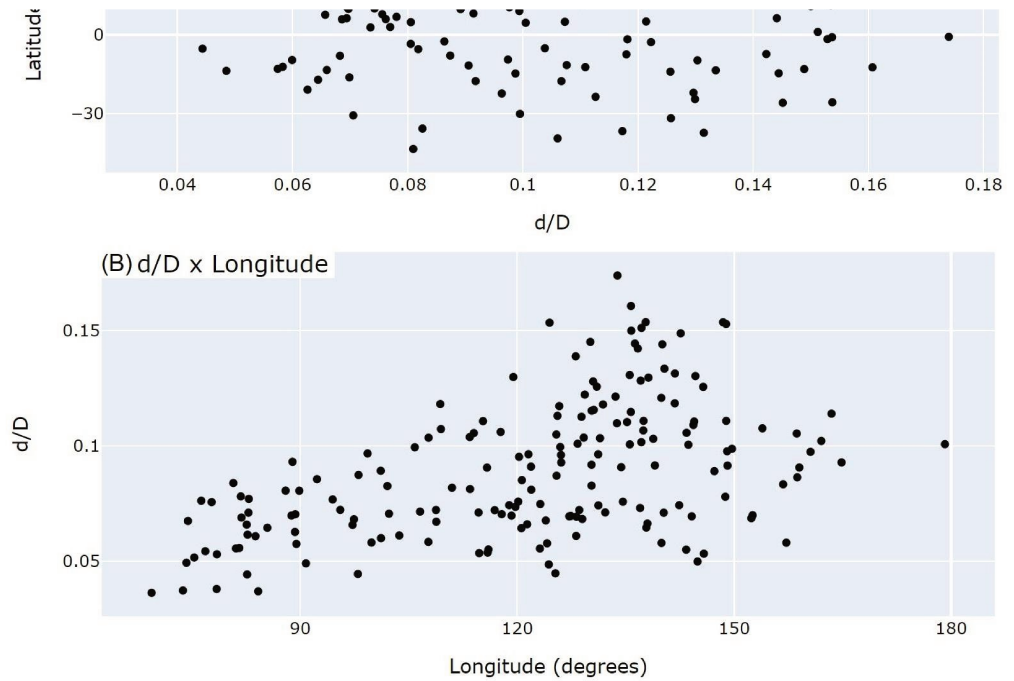


Figure 5. d/D ratios related only to freshest craters plotted according to: (A) latitude; (B) longitude.

In order to better understand the variability of morphometry across Pluto's surface, areas of common d/D patterns were grouped together, using Figure 5 and 6, in five different regions (Figure 6B).

Craters within areas 2 and 3 (i.e., craters within the western - northwestern regions) tend to be shallower than the craters in eastern terrains. Areas 4 and 5 contain the deepest craters of our database comparing structures of the same diameter. Area 1 groups together craters of medium to low d/D values.

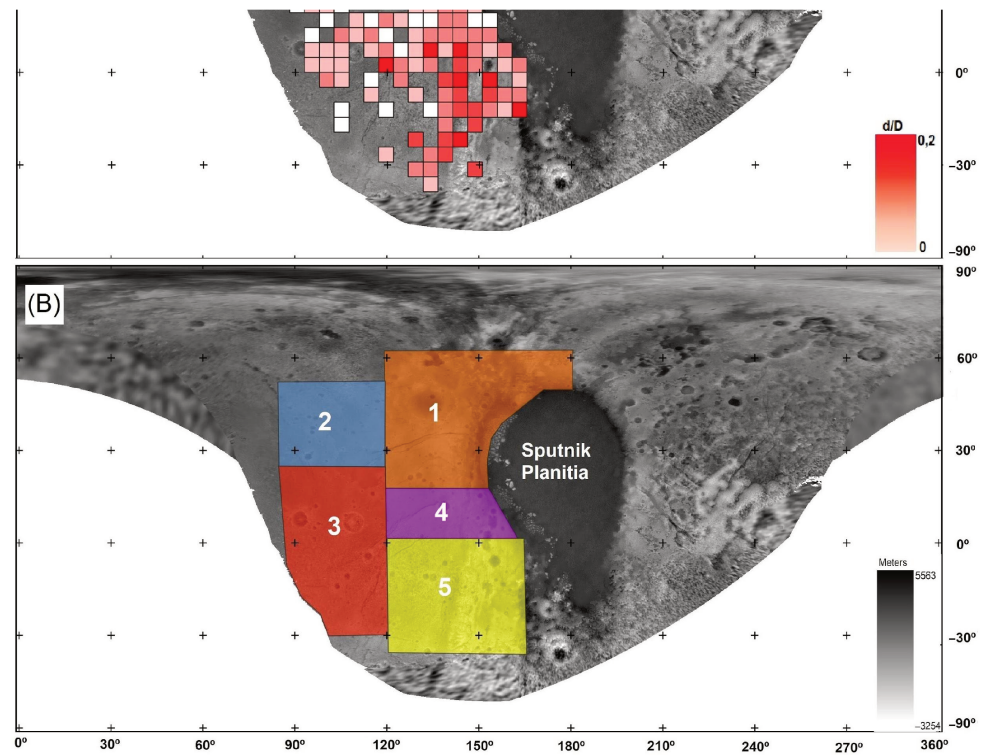


Figure 6. (A) Heatmap showing bins of 100 km^2 with mean values of d/D ratios. Bins with no craters are not considered. (B) Areas dividing Pluto's surface into five groups.

Figure 7A shows the measured values of depth and diameter for the freshest measured craters of all areas, while Figure 7B–F show the same data, but considering separately simple and complex craters within each morphological domain. Craters of areas 1 and 4 show a change of slope trend of the graph approximately in 10 km of diameter (Figure 7B and 7E). Craters within Area 3 and 5 (Figure 7D and 7F) show a change of trend in $\sim 15 \text{ km}$ of diameter. The lack of small craters ($< 12 \text{ km}$) in area 2 limits the comparison between this area and the others, but it is possible to notice that the data collected in it shows that craters $< 12 \text{ km}$ are considerable shallower than craters larger than 15 km.

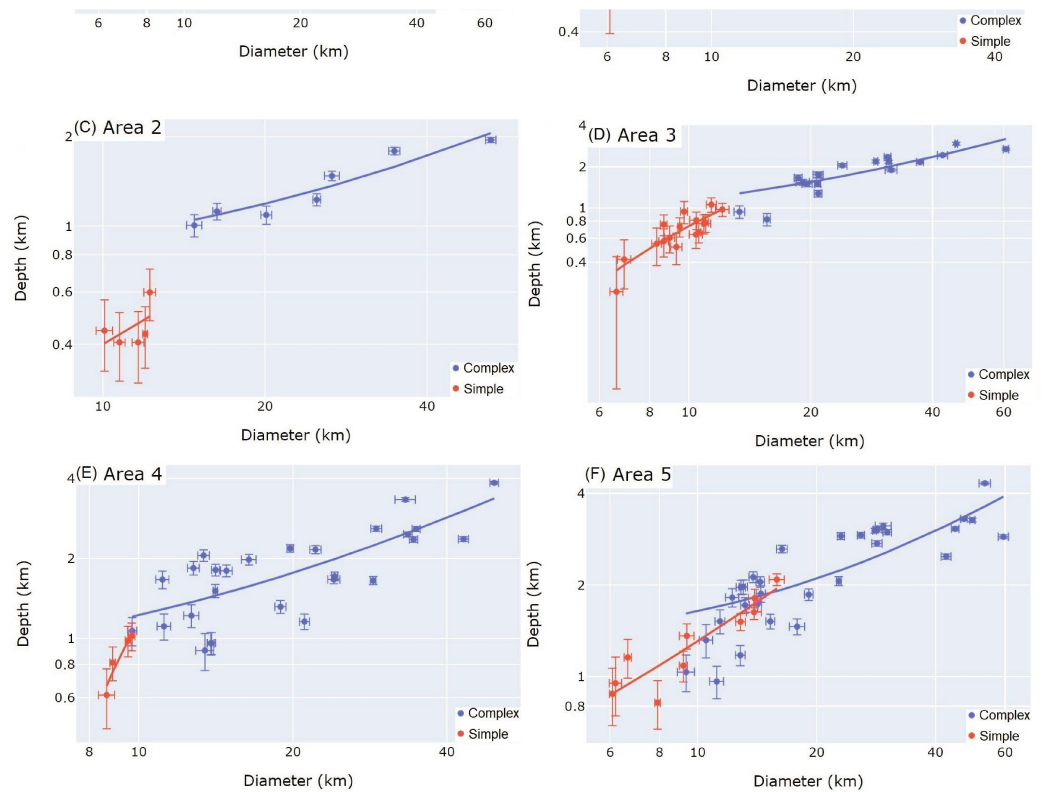


Figure 7. Depth vs Diameter plotted on log–log scale. Only the freshest craters of each area are considered. Data are divided into simple and complex structures. (A) all areas. (B) area 1 (C) area 2. (D) Area 3. (E) Area 4. (F) Area 5.

Figure 8, representing only the freshest craters, shows that craters over 15–20 km in diameter tend to have a smaller d/D ratio in comparison to craters with smaller diameters (<10 km). Also, craters smaller than 15 km of diameter within near equatorial westerns regions (area 4 and some craters of area 5) reach higher depth/diameter ratios ($d/D > 0.1$) compared to crater within northern-northwestern regions.

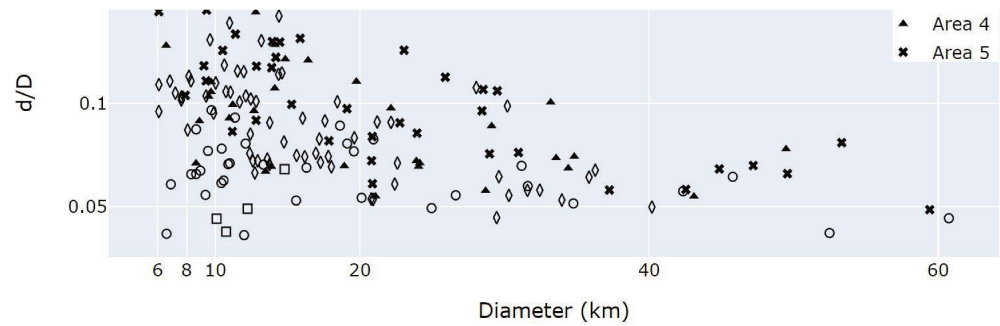


Figure 8. d/D ratio vs Diameter plot of freshest craters only. Note that Area 2 and Area 3 terrains are predominant at the bottom of the plot.

Assuming that the observed width and slope of the internal wall of the impact craters should increase as the craters undergo erosion and filling processes, Figure 9 relates wall width (Ww) with depth of the freshest craters of each area. It shows that craters of areas 4 and 5 tend to remain in the lower values of the plot. Other areas show a similar diversity of ranges for each depth value.

In Figure 10, the depth variation (standard deviation of the rim-floor depths extracted in all profiles of a crater) of all craters is plotted against diameter (Figure 10A) and depth (Figure 10B). There is a positive correlation of increasing diameter and depth as depth variation increases.

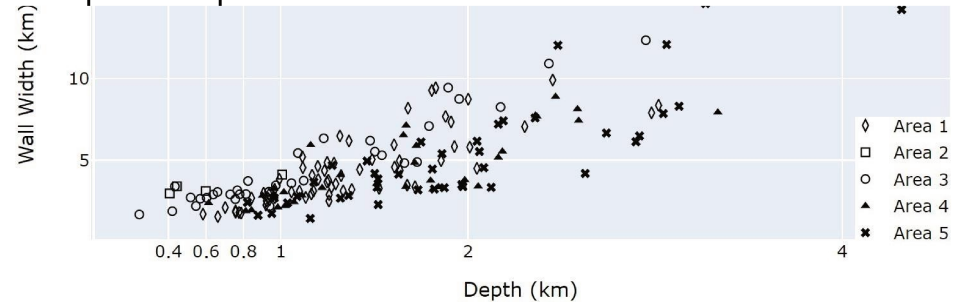


Figure 9. Wall width (Ww) versus depth of the freshest impact craters.

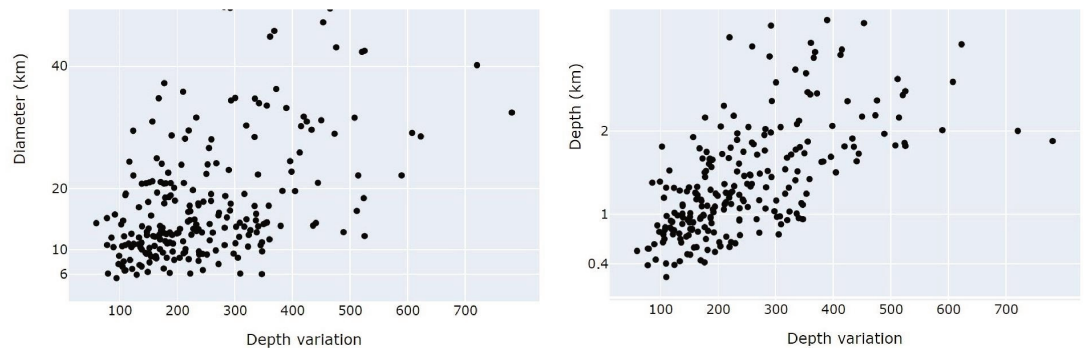


Figure 10. (A) diameter versus depth variation of all craters. (B) Depth versus depth variation of all craters. All craters plotted.

Figure 11 shows the relation of the slope of the inner wall (Sw) with diameter. Most of the craters are concentrated between 10 and 20 degrees of slope of the inner wall. Between 10 and 15 km in diameter there is a considerable presence of craters from areas 4 and 5 on higher slope values. Craters within areas 2 and 3, on the other hand, are concentrated in general in the areas of lower declivity of inner walls. Figure 12A shows a tendency of increasing Sw with depth. As we plot all craters in Figure 12A, it is possible to observe a higher spread of data as slope and depth values increase. To better understand this data spread, three different trends were defined in the chart (see Section 4 “Discussion”). Figure 12B shows a strong linear correlation of Sw and d/D ratios for all craters. The tendency of increasing Sw with depth is better observed when plotting only craters of the same diameter (10–11 km in Figure 12B).

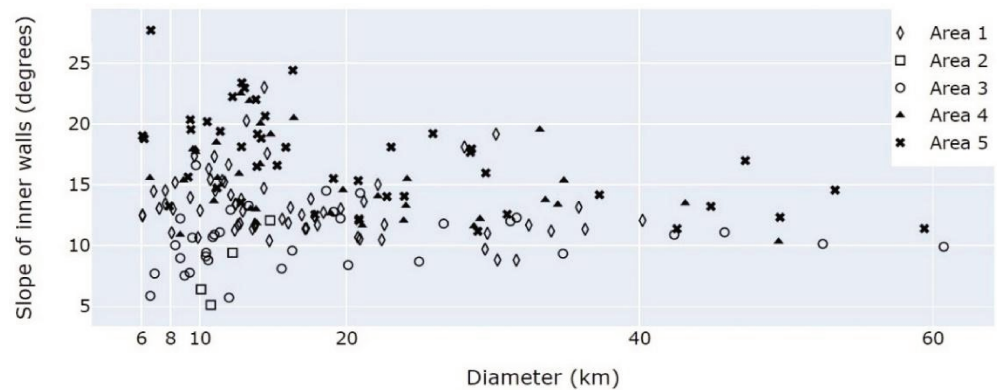


Figure 11. Slope of inner walls (Sw) versus diameter of impact craters. All craters plotted.

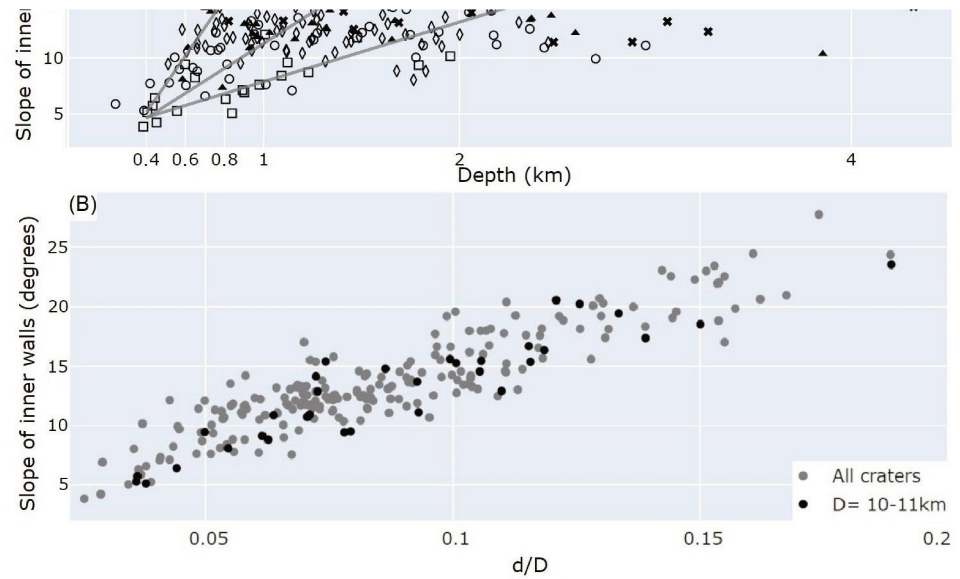


Figure 12. A: slope of inner walls (S_w) versus depth. Lines indicate three different apparent data trends (All craters plotted). B: S_w vs d/D ratios for all craters (gray) and for craters with diameter between 10 and 11 km (black).

Figure 13 shows the relation of depth and the depth variation for a diameter of approximately 10 km. The plot shows a positive linear correlation between the two morphometrics variables. There are three points with large discrepancies (near 1 km depth).

Figures 14A,B show a strong linear correlation of wall width (W_w) and base diameter (D_b) with diameter (D). Both plots show data spreading at 20 km of diameter.

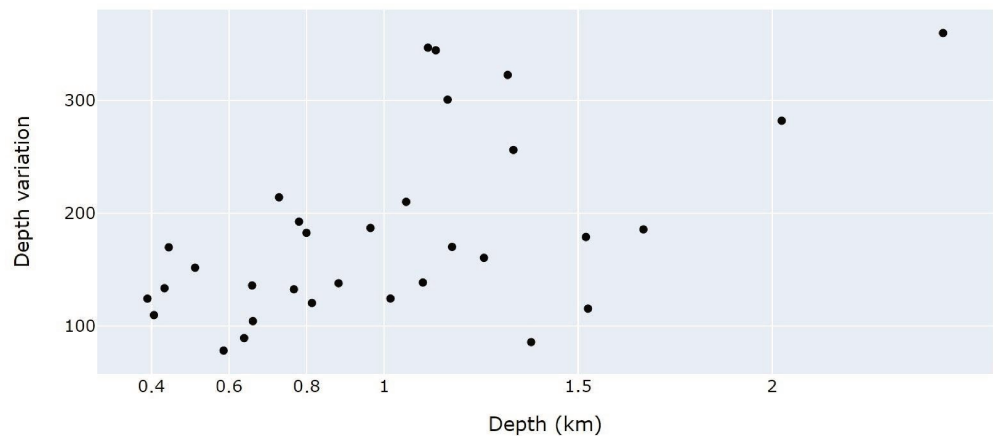


Figure 13. Depth versus depth variation. Data plotted is strictly for craters with approximately 10 km of diameter.

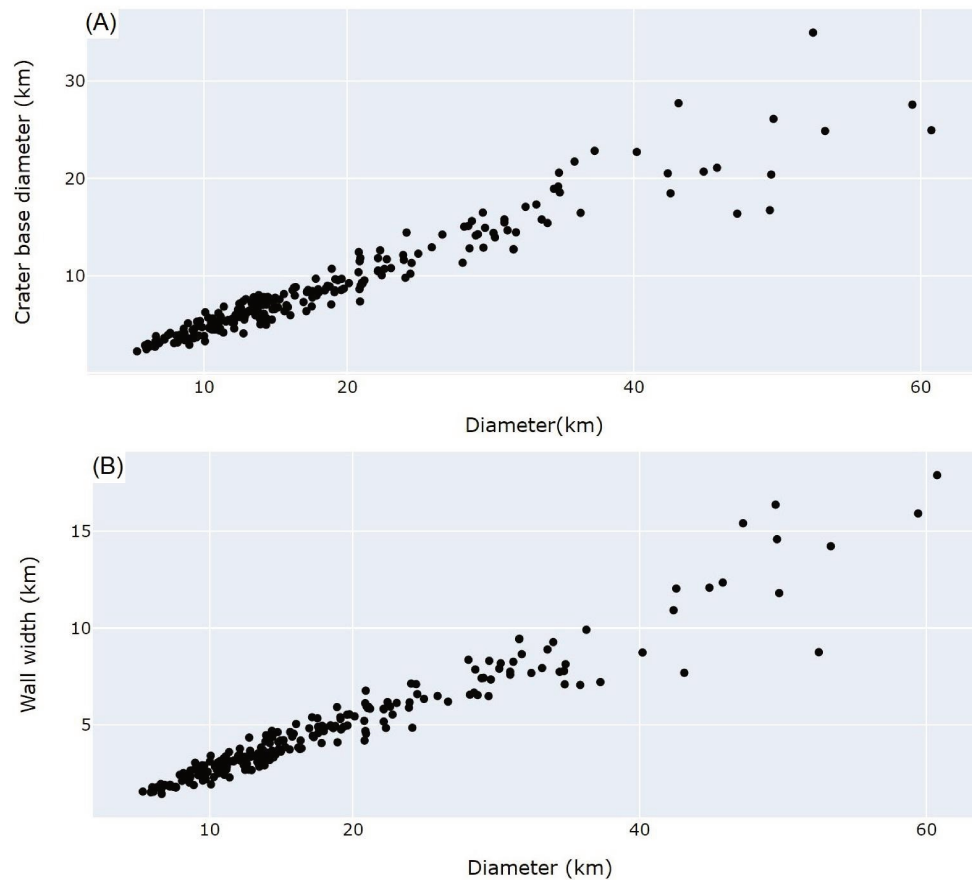


Figure 14. A) Wall width versus diameter. B: Diameter of base versus Diameter. All craters plotted.

4. Discussion

4.1. Transition Diameter

Schenk et al. [11] and Schenk [16], each applying different methods, concluded that the transition diameter between simple and complex craters for Pluto are 4.3 km and 10 km in diameter, respectively. The transition diameter is inversely proportional to the gravity of the body [17]. Knowing that the gravity of Galilean satellites is approximately twice that of Pluto, the transition diameter on Pluto is expected to be twice that on Galilean satellites. In addition, the impact speed on Galilean satellites is approximately 23 km/s [15], whereas on Pluto it is 2 km/s [18]. Therefore, deeper craters are expected to form on Pluto as calculated by Bray and Schenk [15]. Knowing this, a higher d/D ratio for the dwarf planet in comparison with the Galilean satellites is predictable.

Comparing the data for Galilean satellites of Schenk [19] and the results from this study, it is possible to confirm that craters on Pluto are indeed deeper. For example, a crater with 20 km of diameter has a depth of 1 km on Galilean satellites and 2 km on Pluto. Iapetus and Rhea have a lower gravitational acceleration than Pluto, thus, the transition diameter of Pluto must be an intermediate value in between these bodies. The body with gravitational acceleration closest to Pluto is Triton, which has a transition diameter of approximately 11 km in diameter [20].

Schenk et al. [11] measured the diameter and depth of only complex craters on Pluto's surface and used a d/D ratio of 0.2 for unmodified simple craters. Schenk et al. [11] indicated a simple to complex transition diameter of ~ 4.3 km, as expected from the extrapolation of the other icy bodies. Due to the fact that only craters larger than 5 km of diameter were computed in this work, it is not possible to verify the transition diameter proposed by Schenk et al. [11]. However, it is possible to observe a slope change at 10 km, therefore a transition diameter for simple to complex craters of 10 km in areas 1 and 4, as expected based on the calculations of Schenk [16] and Robbins et al. [10]. Areas 3 and 5 show a slope change at approximately 15 km of diameter. Robbins et al. [10] found a transition diameter (D_t) of 10 km for Pluto but, without dividing it in different terrains, it was not possible to observe a different D_t for different regions as reported here. Robbins et al. [10] interpreted that a higher proportion of rocks in Pluto's crust could explain the fact that the D_t in the dwarf planet is higher than expected from the extrapolation of the D_t from other icy bodies. So, a basic interpretation of the areas with $D_t \sim 15$ km found in this work could be that, in these areas, the crust could contain a higher percentage of rocky materials mixed with ice in comparison to the rest of Pluto. Also, visual analysis was conducted to separate complex craters from simple craters mainly using the following features: flat base (complex) and parabolic base (simple), and presence or absence of a central peak. It is possible to observe craters up to a maximum of ~ 16 km of diameter with features compatible with simple craters. Other craters with at least ~ 9 km of diameter contain features compatible with complex structures. This indicates that the transition diameter may be in the range between 9 and 16 km.

4.2. Morphometric Differences

Taking into account the analysis of deeper craters to define the freshest structures (Figure 5A), craters at latitude close to 0° and longitude between 150° and 120° have the highest variation of depths for a given diameter, which could indicate a variability in modification rates in these areas. It is noteworthy that the analysis of the deepest craters, within the same area and the same diameter range, indicates the least modified ones. However, in a few cases, some craters in the group of the deepest ones may have been modified by overlapping craters, which can artificially increase their depth. Visual analysis shows only a few cases of overlapping craters, so the method of deepest craters appears to be efficient for statistical analysis.

Considering only the western region of Sputnik Planitia (SP), where data were collected for this work, the craters located between longitude 150° and 120° and latitude 15° and -30° have higher d/D ratios than the westernmost craters (longitude $<120^\circ$) and northernmost craters (latitude $>30^\circ$). Since craters located within areas 4 and 5 are usually the deepest craters of Pluto for almost every diameter (analyzing the freshest craters only), this could explain the higher d/D ratios of these areas (Figure 6). As the DEM available for Pluto does not cover latitudes beyond -30° (Figure 2), it impairs the analysis if there are differences between morphometries in low latitudes, as those that we can find in higher latitudes.

Singer et al. [7] estimated that the whole western part of Sputnik Planitia is very old and has approximately the same age. Therefore, it is impractical to associate the morphometry difference with the age of the dwarf planet's surface. However, we can associate the morphometric differences between northern and equatorial/southern regions with a higher rate of modification. Low depths in the northern-northwestern regions may be due to sublimation of volatiles (discussed below). A constant deposition

during the different seasons of Pluto could also end up eroding and modifying the craters in a more intense way in the northern-northwestern regions, compared to the equatorial regions [12].

As the lower limit of d/D ratio in almost all longitude ranges is similar (Figure 5B), the difference in d/D ratio between them does not necessarily indicate the western part has undergone greater modification. Rather, the newly formed craters further to the west could be shallower compared to craters of the same diameter in the eastern regions. On the other hand, Figure 5A shows that the lower limit of d/D values increases from north to south, which could indicate a lower degree of modification towards lower latitudes. Yet, another hypothesis would be that the modification processes in the northwestern region (mainly area 2) could be sufficient to erode a larger number of craters and eliminate craters with higher d/D values, compared to the equatorial regions that concentrate craters with a wide range of d/D values. The spatial location of the equatorial craters exhibiting a great variability in d/D ratios is concentrated in a restricted area of Pluto, and not randomly placed throughout its surface, reinforcing the idea that these craters were formed in a region with similar rheology.

Comparing the regions with the highest d/D values, it is possible to observe differences in morphometry. Simple craters in area 5 are deeper than craters in area 4. Knowing that deepest craters should represent the least modified structures, the difference in depth could represent a different modification state between equatorial and southern craters.

Larger craters tend to be formed earlier in the Solar System, so they accumulate more superimposed impacts and are affected by deformation processes for a longer period of time. On the other hand, smaller craters are more susceptible to these changes, so rim degradation and infilling by wall collapse would be more effective in reducing the d/D ratios of smaller craters (shallow ones) than the large (deeper) ones [21]. This pattern is shown in Figure 8, which depicts that craters with 10 km or less of diameter (taking into account the same terrain) have a greater range in the d/D ratio, which may indicate a higher rate of modification for craters in this size range. Figure 11 shows that smaller diameter craters tend to have a greater slope variability, which may show that the smaller the craters are, the more affected by filling or mass waste they are, factors that can decrease the slope of the wall. Larger craters do not appear to be so susceptible to decreases in the crater's slope, which agrees with the work by White et al. [21].

Craters of the same age and region, within the same diameter range, should have the same depth and other morphometric aspects. When separating the data of the plot showing slope vs d/D in craters with diameters between 10 and 12 km (Figure 12B), it is possible to observe that the shallower the crater is, the lower is the slope of the inner wall. According to Figure 12B, craters with lower d/D ratios in the same region have lower slopes in the inner walls. It is possible to assume that the more modified a crater is, the lower the slope angle of the inner walls of the structure will be, perhaps due to mass wasting.

Considering that pristine craters across Pluto's surface have similar morphometry, Figure 12 shows three different trends that could indicate different levels of modification. The slope of the inner wall should decrease with increasing modification, then the trend #3 shown in Figure 12 may represent the most modified craters by infilling, mass waste or ice relaxation. In this figure it is possible to observe that the higher values (least modified craters) are dominated by craters within areas 4 and 5 (and some craters of area 1) and that craters within areas 2 and 3 are concentrated

under 15° of slope (higher rates of modification). Figure 11 shows that craters larger than 15 km tend to decrease d/D ratios. When observing the plot using only craters smaller than 15 km, the ones that have a lower d/D ratio are craters that must have undergone more modification due to infilling or ice relaxation.

It is possible to verify a difference in trend for craters with diameter greater than 20 km in different figures in this work (Figures 11, 14A, 14B). Figure 11 shows that craters over 20 km of diameter exhibit a smaller slope. Figure 14A and 14B show that craters larger than 20 km tend to present more spread data. This observation may be an indication of ice relaxation, since this process generally affects larger craters [7], [21], [22].

Crater of the same age with low depths within the same morphological terrain and same diameter might indicate high levels of modification. The pattern of Figure 13 may mean that the smaller depth variation represents the most deformed craters, since erosion may have deformed the entire rim equally. On the other hand, well-preserved craters may have a high rate of standard deviation from the rim due to topography interference or may indicate that erosion have not yet degraded all the rim equally. This differs from what was previously thought, namely that high depth variation should represent high levels of modification of impact craters. The anomalous points in Figure 13 may represent those with higher levels of modification or terrain influence previously to the crater formation.

Robbins and Hynek [4] gathered an extensive database of Mars impact craters ≥ 1 km, and found that craters near equatorial regions are deeper than the ones in areas of high latitudes. The authors concluded that the volatiles present near the poles could melt during crater formation and fill the crater during the modification phase, therefore making them shallower. Figure 7A shows that the most pristine craters within areas 4 and 5 tend to be deeper for a given diameter than in the western-northwestern regions. These differences related to the deepest craters could represent a change in rheology between different regions of Pluto's surface, a suggestion presented by Robbins and Hynek [4] and Watters et al. [6]. As shown in Section 4.1, the different transition diameters found in each area could also be explained by the respective different proportions of ice and rock materials. Also, another hypothesis to explain the morphometric differences between regions on Pluto could be due to the presence of volatiles during the formation of the crater (during its modification stage), when the impact energy melts the volatiles that, subsequently, fill the crater [4].

According to Grundy et al. [12], there is evidence for mantling, or covering of a terrain with a new layer of material in Pluto's surface. This is most clearly observed in Pluto's northern areas, with the presence of N_2 , CO, and CH_4 ices, that are all volatile at surface temperatures of 35 to 50 K. Of the three compounds, N_2 has the highest vapor pressure and thus dominates the lower atmosphere [12]. Many craters in western regions above 0° of latitude, show strong CH_4 absorption on their rims but not on their floors [12]. N_2 absorption appears strongest on many crater floors, notably those in the northern regions, where partially filled larger craters are found, implying that smaller craters may be completely buried by mantling [7], [12]. Since impacts on nitrogen layers above water generate deeper craters with smaller diameter [23], in the case of Pluto the lower d/D ratio for northern regions (which shows strong presence of N_2), could be due to the N_2 being responsible for infilling the craters by atmospheric deposition rather than being influenced during the impact process. This does not exclude the possibility that other volatiles are interfering with the formation of impact structures, turning shallower craters in the northern regions of Pluto. In the same way, the strong presence of volatile

CH₄ in the craters' rim from areas 2 and 3 could also explain the low values for d/D in these regions, either influencing the crater formation or post-modifying it.

Visual analysis of the images does not allow to identify classes of modification rate in different regions, since the entire western part of Sputnik Planitia has a similar age and lack of well-preserved craters. Since the presence of volatile elements in the northern part of Pluto indicates greater levels of erosion rate, it is simpler to assume that the rate of erosion at higher latitudes is high. Therefore, the wide range of variability of the data in the equatorial regions may indicate that the modifying processes in the equatorial regions were not sufficient to erode and modify all the craters compared to the northernmost regions. Or, the presence of volatiles at the surface regions of higher latitudes makes the surface weaker during the modification stage of crater formation, emphasizing the infilling during the formation process.

It is important to highlight that these differences in the morphometric data could be due to differences in the spatial resolution of the images used to construct the DEM. The spatial resolution between regions where the craters were collected varies between 80 and 300 m/pixel, while the vertical accuracy varies between 100 and 800 m [11]. A comparison made by Schenk [22] of Mercurian crater depths in images with spatial resolutions from 0.2 to ~1 km/pixel indicated little significant loss of depth information at these resolutions. As the resolution between the images used to obtain the crater data presented here varies by approximately 400 m/pixel, contemplating a variation significantly less than that tested by Schenk [22], the difference in the morphometric data in the different Pluto resolution zones [7], [16] should not statistically influence the comparison of data. In addition, there is a group of craters within areas 1 and 2 that are in the same resolution zone, further demonstrating that it should not be the resolution that is influencing the difference in the morphometric data. So, we can assume two hypotheses: that our data will be little affected by the difference in resolution or, otherwise, that the DEM generated by stereogrammetry behaves differently from the photoclinometry data used by Schenk [22].

5. Conclusions

We have reported on the analysis of differences in morphometric characteristics throughout Pluto's surface for a globally and locally distributed population of craters. We have conducted a detailed study of crater morphometry using craters in the range from 5 to 60 km of diameter.

We have found that craters within areas 1 and 4 exhibit a simple to complex diameter transition (D_t) of ~10 km and craters within areas 3 and 5 exhibit a D_t of ~15 km. This difference suggests that there are some possible compositional differences throughout Pluto's crust. Since the transition diameter found in this work is higher than expected by the extrapolation from other icy bodies, we can assume that the crust of Pluto contains a higher percentage of rocky material than the Galilean satellites [10]. We also observed that craters within areas 1 and 2 are shallower than in other regions. This could be due to the presence of volatiles (mainly CH₄ and N₂) in those regions, that could influence crater morphology during its formation or during the volatile sublimation cycles. Equatorial craters have a higher range of depth values for a given diameter. This could be related to less intense modification processes in the equatorial regions, that were incapable of modifying all the craters. Craters larger than 20 km tend to exhibit smaller slopes of inner walls and higher data spread. This could be due to a modification process that affects mainly larger craters, such as ice relaxation.

The results presented here provide new insights on the relationships between morphometric parameters and terrain dependence, offering constraints for modeling landscape evolution and crater formation. Future works encompassing a detailed geological map of Pluto will contribute to understanding the dynamics of impact cratering on Pluto and provide further supporting evidence for the morphometric characterization of Pluto's surface.

In summary, the conclusions attained in this work are:

1. The transition from simple to complex craters in Pluto varies between 10 km (areas 1 and 4) and 15 km diameter (areas 3 and 5). This indicates that the dynamics of impact crater formation on Pluto is between the ones of icy and rocky bodies and do not follow the trend of icy bodies as expected from the inverse-gravity relationship.
2. Low slopes of inner walls and a high spread of data for craters greater than 20 km in diameter may indicate a modification process that has affected mainly larger craters.
3. Equatorial craters have a higher range of depth values for a given diameter. This could be related to less intense modification processes presented in the equatorial regions in modifying all the craters.
4. Differences in morphometry in each area could be related to different rheological properties of the target materials, explained by a higher proportion of rocky material in relation to other materials (ice) in area 3 and 5, as well as the presence of volatiles in area 1 and 2,
5. Volatile elements could be responsible for the incidence of shallower craters in the northern and northwestern regions. Volatile ices could influence crater formation and/or modify craters during Pluto's different seasons.

Supplementary Materials: The following materials are available online at <https://www.mdpi.com/2072-4292/13/3/377/s1>; Figure S1: Flowchart summarizing the Python code logic; Table S1: Complete data; Appendix S1: Python Code; Complete Python code available online at: <https://github.com/caiovnv/Impact-crater-morphometry->

Author Contributions: Conceptualization, A.P.C. and C.V.N.V.; methodology, A.P.C., C.V.N.V., and C.H.G.; software, C.V.N.V.; formal analysis: C.V.N.V.; writing—original draft preparation, C.V.N.V.; writing—review and editing, C.V.N.V., A.P.C., and C.H.G.; supervision, A.P.C. and C.H.G. All authors have read and agreed to the published version of the manuscript.

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Anexo 2. Código Python

```

Crater = "
output = "
slopeproj=
demproj =
dem =
slope =

csv_file =
output_pc =
output_me =
output_me_select =
output_pc_select =
output_line =
output_merge =
output_base =
output_merge_baserim =
output_line_slope =
output_alllines =
output_poly =

#----- Reprojection -----
point = iface.activeLayer()
feat = point

fieldcalc = processing.run("qgis:fieldcalculator",
{'INPUT':feat,'FIELD_NAME':'x','FIELD_TYPE':0,'FIELD_LENGTH':10,'FIELD_PRECISION':3,'NEW_FIELD':True,'FORMULA':'to_dm(x(transform($geometry,\ 'USER:100000\','\ 'EPSG:104969\')), \ 'x\ ', 2),'OUTPUT':'memory:'})

fieldcalc2 = processing.run("qgis:fieldcalculator",
{'INPUT':fieldcalc['OUTPUT'],'FIELD_NAME':'y','FIELD_TYPE':0,'FIELD_LENGTH':10,'FIELD_PRECISION':3,'NEW_FIELD':True,'FORMULA':'to_dm(y(transform($geometry,\ 'USER:100000\','\ 'EPSG:104969\')), \ 'x\ ', 2),'OUTPUT':'memory:'})

layer = fieldcalc2['OUTPUT']
featfeat=layer.getFeatures()#get first feature
list_coord =[]

```

```

for featurecent in featfeat:
    list_coord.append(featurecent['x'])
    list_coord.append(featurecent['y'])

my_crs = QgsCoordinateReferenceSystem()
my_crs.createFromProj4("+proj=stere +lat_0="+list_coord[1]+" +lon_0="+list_coord[0]+" +x_0=0 +y_0=0
+a=1188300 +b=1188300 +units=m +no_defs")
my_crs.saveAsUserCrs("crater")
QgsProject.instance().setCrs(my_crs)

buff =processing.run("native:buffer",
{'INPUT':feat,'DISTANCE':100000,'SEGMENTS':5,'END_CAP_STYLE':0,'JOIN_STYLE':0,'MITER_LIMIT':2,'DISSOLVE':False,'OUTPUT':'TEMPORARY_OUTPUT'})
clip=processing.run("gdal:clprasterbymasklayer",
{'INPUT':dem,'MASK':buff['OUTPUT'],'SOURCE_CRS':None,'TARGET_CRS':None,'NODATA':None,'ALPHA_BAND':False,'CROP_TO_CUTLINE':True,'KEEP_RESOLUTION':False,'SET_RESOLUTION':False,'X_RESOLUTION':None,'Y_RESOLUTION':None,'MULTITHREADING':False,'OPTIONS':','DATA_TYPE':0,'OUTPUT':'TEMPORARY_OUTPUT'})
clip2=processing.run("gdal:clprasterbymasklayer",
{'INPUT':slope,'MASK':buff['OUTPUT'],'SOURCE_CRS':None,'TARGET_CRS':None,'NODATA':None,'ALPHA_BAND':False,'CROP_TO_CUTLINE':True,'KEEP_RESOLUTION':False,'SET_RESOLUTION':False,'X_RESOLUTION':None,'Y_RESOLUTION':None,'MULTITHREADING':False,'OPTIONS':','DATA_TYPE':0,'OUTPUT':'TEMPORARY_OUTPUT'})

layer1 = QgsRasterLayer(clip['OUTPUT'])
layer2 = QgsRasterLayer(clip2['OUTPUT'])

crsup = iface.mapCanvas().mapSettings().destinationCrs().authid()
warp1 = processing.run("gdal:warpproject",
{'INPUT':layer1,'SOURCE_CRS':QgsCoordinateReferenceSystem('USER:100000'),'TARGET_CRS':QgsCoordinateReferenceSystem(crsup),'RESAMPLING':0,'NODATA':None,'TARGET_RESOLUTION':None,'OPTIONS':','DATA_TYPE':0,'TARGET_EXTENT':None,'TARGET_EXTENT_CRS':None,'MULTITHREADING':False,'EXTRA':','OUTPUT':output_dem})
warp2 = processing.run("gdal:warpproject",
{'INPUT':layer2,'SOURCE_CRS':QgsCoordinateReferenceSystem('USER:100000'),'TARGET_CRS':QgsCoordinateReferenceSystem(crsup),'RESAMPLING':0,'NODATA':None,'TARGET_RESOLUTION':None,'OPTIONS':','DATA_TYPE':0,'TARGET_EXTENT':None,'TARGET_EXTENT_CRS':None,'MULTITHREADING':False,'EXTRA':','OUTPUT':output_slope})

#-----Delineation -----

```

```

poly = iface.activeLayer()

save_poly = QgsVectorFileWriter.writeAsVectorFormat(poly, output_poly , "UTF-8", poly.crs(), "ESRI
Shapefile")

list_data = []
list_data2 = [list_data]
list_data.append("+crater+")
crs = iface.mapCanvas().mapSettings().destinationCrs().authid()
fieldcalculator1 = processing.run("qgis:fieldcalculator",
    {'INPUT': poly, 'FIELD_NAME': '1.3-field', 'FIELD_TYPE': 0, 'FIELD_LENGTH': 10,
'FIELD_PRECISION': 3,
    'NEW_FIELD': True,
    'FORMULA': '((length(shortest_line(centroid($geometry),boundary($geometry)))))*1.3',
    'OUTPUT': 'memory:'})
fieldcalculator2 = processing.run("qgis:fieldcalculator",
    {'INPUT': poly, 'FIELD_NAME': '1-4_raio', 'FIELD_TYPE': 0, 'FIELD_LENGTH': 10,
'FIELD_PRECISION': 3,
    'NEW_FIELD': True,
    'FORMULA': '((length(shortest_line(centroid($geometry),boundary($geometry)))))/4.5',
    'OUTPUT': 'memory:'})
fieldcalculator3 = processing.run("qgis:fieldcalculator",
    {'INPUT': poly, 'FIELD_NAME': '8_raio', 'FIELD_TYPE': 0, 'FIELD_LENGTH': 10,
'FIELD_PRECISION': 3,
    'NEW_FIELD': True,
    'FORMULA': '((length(shortest_line(centroid($geometry),boundary($geometry)))))/8',
    'OUTPUT': 'memory:'})
polytoline = processing.run("native:polygonstolines", {'INPUT': fieldcalculator2['OUTPUT'], 'OUTPUT':
'TEMPORARY_OUTPUT'})
centroid = processing.run("saga:polygoncentroids",
    {'POLYGONS': fieldcalculator1['OUTPUT'], 'METHOD': 'Centroid', 'CENTROIDS':
'TEMPORARY_OUTPUT'})
buffervar = processing.run("saga:variabledistancebuffer",
    {'SHAPES': centroid['CENTROIDS'], 'DIST_FIELD': '1.3-field', 'DIST_SCALE': 1, 'NZONES':
1, 'DARC': 5,
    'DISSOLVE': True, 'POLY_INNER': False, 'BUFFER': 'TEMPORARY_OUTPUT'})
polytoline2 = processing.run("native:polygonstolines", {'INPUT': buffervar['OUTPUT'], 'OUTPUT':
'TEMPORARY_OUTPUT'})
desify = processing.run("native:densifygeometriesgivenaninterval",
    {'INPUT': polytoline2['OUTPUT'], 'INTERVAL': 600, 'OUTPUT': 'TEMPORARY_OUTPUT'})
vertice = processing.run("native:extractvertices", {'INPUT': desify['OUTPUT'], 'OUTPUT':

```

```

'TEMPORARY_OUTPUT'})
geometry = processing.run("qgis:exportaddgeometrycolumns",
    {'INPUT': vertice['OUTPUT'], 'CALC_METHOD': 0, 'OUTPUT': 'TEMPORARY_OUTPUT'})
geometry2 = processing.run("qgis:exportaddgeometrycolumns",
    {'INPUT': centroid['CENTROIDS'], 'CALC_METHOD': 0, 'OUTPUT':
'TEMPORARY_OUTPUT'})
fieldcalculator4 = processing.run("qgis:fieldcalculator",
    {'INPUT': geometry2['OUTPUT'], 'FIELD_NAME': 'ID', 'FIELD_TYPE': 0, 'FIELD_LENGTH':
10,
    'FIELD_PRECISION': 3, 'NEW_FIELD': True, 'FORMULA': '0', 'OUTPUT': 'memory:'})
join = processing.run("native:joinattributetable",
    {'INPUT': geometry['OUTPUT'], 'FIELD': 'ID', 'INPUT_2': h2['OUTPUT'], 'FIELD_2': 'ID',
'FIELDS_TO_COPY': [],
    'METHOD': 1, 'DISCARD_NONMATCHING': False, 'PREFIX': "", 'OUTPUT':
'TEMPORARY_OUTPUT'})
xyline = processing.run("shapetools:xy2line",
    {'InputLayer': join['OUTPUT'], 'InputCRS': QgsCoordinateReferenceSystem(crs),
'OutputCRS': QgsCoordinateReferenceSystem(crs), 'LineType': 0, 'StartUseLayerGeom':
False,
    'StartXField': 'xcoord_2', 'StartYField': 'ycoord_2', 'EndUseLayerGeom': False,
'EndXField': 'xcoord', 'EndYField': 'ycoord', 'ShowStartPoint': True, 'ShowEndPoint': True,
'DateLineBreak': False, 'OutputLineLayer': 'TEMPORARY_OUTPUT',
'OutputPointLayer': 'TEMPORARY_OUTPUT'})
profile = processing.run("saga:profilesfromlines",
    {'DEM': dem, 'VALUES': "", 'LINES': j['OutputLineLayer'], 'NAME': 'fid', 'SPLIT': False,
'PROFILE': 'TEMPORARY_OUTPUT', 'PROFILES': 'TEMPORARY_OUTPUT'})
valuetopoint = processing.run("saga:addrastervaluestopoints",
    {'SHAPES': profile['PROFILE'], 'GRIDS': slope, 'RESAMPLING': 0, 'RESULT':
'TEMPORARY_OUTPUT'})
buffervar2 = processing.run("saga:variabledistancebuffer",
    {'SHAPES': polytoline['OUTPUT'], 'DIST_FIELD': '1-4_raio', 'DIST_SCALE': 1, 'NZONES': 1,
'DARC': 5,
    'DISSOLVE': True, 'POLY_INNER': False, 'BUFFER': 'TEMPORARY_OUTPUT'})
clip = processing.run("saga:clippointswithpolygons",
    {'POINTS': valuetopoint['RESULT'], 'POLYGONS': m['BUFFER'], 'FIELD': 'Drawings',
'METHOD': 0,
    'CLIPS': 'TEMPORARY_OUTPUT'})
centroid2 = processing.run("saga:polygoncentroids",
    {'POLYGONS': fieldcalculator3['OUTPUT'], 'METHOD': True, 'CENTROIDS':
'TEMPORARY_OUTPUT'})
buffervar3 = processing.run("saga:variabledistancebuffer",

```

```

        {'SHAPES': centroid2['CENTROIDS'], 'DIST_FIELD': '8_raio', 'DIST_SCALE': 1, 'NZONES':
1, 'DARC': 5,
        'DISSOLVE': True, 'POLY_INNER': False, 'BUFFER': 'TEMPORARY_OUTPUT'})
difference = processing.run("native:difference", {'INPUT': valuetopoint['RESULT'], 'OVERLAY':
a5['BUFFER'], 'OUTPUT': 'TEMPORARY_OUTPUT'})

layer11 = difference['OUTPUT']
QgsProject.instance().addMapLayer(layer11)
layer1 = QgsVectorLayer(clip['CLIPS'])
QgsProject.instance().addMapLayer(layer1)

# Maximum Elevation
byexoress = processing.run("qgis:selectbyexpression",
        {'INPUT': layer1, 'EXPRESSION': '"Z" = maximum("z", "LINE_ID")', 'METHOD': 0})
saveselected = processing.run("native:savesselectedfeatures", {'INPUT': layer1, 'OUTPUT': output_me})
layer1.removeSelection()
layer2 = QgsVectorLayer(o2['OUTPUT'])

# Delineation
all_features = layer2.getFeatures()
all_features2 = layer2.getFeatures()
all_features3 = layer2.getFeatures()

lista_repetition = []
for alllineids in all_features:
    lista_repetition.append(alllineids['LINE_ID'])
repetition = max(lista_repetition)

lista_repetition2 = []
for alllineids2 in all_features2:
    lista_repetition2.append(alllineids2['LINE_ID'])
repetition2 = max(lista_repetition2)

lista_repetition3 = []
for alllineids3 in all_features3:
    lista_repetition3.append(alllineids3['LINE_ID'])
repetition3 = max(lista_repetition2)

layer1.startEditing()
layer2.startEditing()

```

```

layer11.startEditing()
idx1 = layer2.fields().indexOfName('LINE_ID')
u1 = layer2.minimumValue(idx1)
processing.run("qgis:selectbyexpression",
               {'INPUT': layer2, 'EXPRESSION': '\ "fid\" = maximum (\ "fid\" ,\ "LINE_ID\" )
AND \ "LINE_ID\" = {}'.format(u1),
               'METHOD': 0})
selected_features = layer2.selectedFeatures()
for point in selected_features:
    u2 = point['fid']
#print(u1)
#print(u2)
exp_me0 = QgsExpression("\ "LINE_ID\" ='{}'.format(u1) AND \ "fid\" ='{}'.format(u1, u2))
feature_me = layer2.getFeatures(QgsFeatureRequest(exp_me0))
x = u1
lista = list(map(str, range(repetition + 1)))
listlayer1 = []
listlayer2 = []
for f in feature_me:
    geom_me0 = f.geometry()
for times in range(repetition + 1):
    x = x + 1
    #print('for1')
    #print(x)
    y = 0
    try:
        lineid = lista[x]
    except IndexError:
        continue
    exp_me = QgsExpression("\ "LINE_ID\" = (' + lineid + ')')
    exp_control = QgsExpression("\ "LINE_ID\" = (' + lineid + ')')
    feature_me = layer2.getFeatures(QgsFeatureRequest(exp_me))
    feature_control = layer1.getFeatures(QgsFeatureRequest(exp_control))
    for f_me in feature_me:
        geom_me = f_me.geometry()
        dist2 = geom_me0.distance(geom_me)
        #print('forme')
        # print(f_me['ID'])
        # print(lineid)
        if dist2 < 1000:
            geom_me0 = geom_me

```



```

#print('me')
#print(f_me['LINE_ID'])
#print(f_me['ID'])
layer2.select(f_me.id())
break
else:
    list_id_key = []
    list_dist_value = []
    list2_id_key = []
    list2_dist_value = []
    for f_control in feature_control:
        geom_control = f_control.geometry()
        dist3 = geom_me0.distance(geom_control)
        list_id_key.append(f_control['ID'])
        list_dist_value.append(dist3)
        keys = list_id_key
        values = list_dist_value
        dictionary = dict(zip(keys, values))
        dictionary2 = dict(zip(keys, values))
    list_pcid = []
    for times in range(3):
        min_val = min(dictionary.values())
        for k, v in dictionary.items():
            if v == min_val:
                list_pcid.append(k)
                del dictionary[k]
            break
    lista2 = list(map(str, list_pcid))
    y = 0
    for times in range(3):
        lineid2 = lista2[y]
        exp_control2 = QgsExpression('\ "ID\ " = ( ' + lineid2 + ' ) ')
        feature_pcid1 = layer1.getFeatures(QgsFeatureRequest(exp_control2))
        y = y + 1
        for f_pcid1 in feature_pcid1:
            feature_pcid1_geom = f_pcid1.geometry()
            dist4 = geom_me.distance(feature_pcid1_geom)
            list2_id_key.append(f_pcid1['ID'])
            list2_dist_value.append(dist4)
    ke = list2_id_key
    va = list2_dist_value

```

```

dictionary_dist = dict(zip(ke, va))
min_val2 = min(dictionary_dist.values())
for ky, vs in dictionary_dist.items():
    if vs == min_val2:
        new_select_pcid = ky
pc_slect_str = str(new_select_pcid)
exp_control3 = QgsExpression("\ID\" = (' + pc_slect_str + ') ")
feature_pcid2 = layer1.getFeatures(QgsFeatureRequest(exp_control3))
for pc_feature in feature_pcid2:
    geom_me0 = pc_feature.geometry()
    #print('pc1')
    #print(pc_feature['LINE_ID'])
    #print(pc_feature['ID'])
    # print(list_pcid)
    # print(dictionary_dist)
    # print(new_select_pcid)
    layer1.selectByExpression("\ID\" IN (' + pc_slect_str + ')", QgsVectorLayer.AddToSelection)
break

listtostr = list(map(str, listlayer1))
p = 0
for feature in listlayer1:
    pointtoselect = listtostr[p]
    layer1.selectByExpression("\ID\" IN (' + pointtoselect + ')", QgsVectorLayer.AddToSelection)
    p = p + 1

saveselected_pc = processing.run("native:savesselectedfeatures", {'INPUT': layer1, 'OUTPUT':
output_pc_select})
saveselected_me = processing.run("native:savesselectedfeatures", {'INPUT': layer2, 'OUTPUT':
output_me_select})

layer_pc_select = QgsVectorLayer(saveselected_pc['OUTPUT'])
layer_me_select = QgsVectorLayer(saveselected_me['OUTPUT'])

merge = processing.run("native:mergevectorlayers",
    {'LAYERS': [layer_pc_select, layer_me_select], 'CRS': None, 'OUTPUT': output_merge})

pointtopath = processing.run("qgis:pointstopath",
    {'INPUT': merge['OUTPUT'], 'ORDER_FIELD': 'LINE_ID', 'GROUP_FIELD': None,
'DATE_FORMAT': "",
    'OUTPUT':output_line})

```

```

layer_line = QgsVectorLayer(merge['OUTPUT'])
QgsProject.instance().addMapLayer(layer_line)

# rim hight
import statistics

layer_points = QgsVectorLayer(merge['OUTPUT'])
feature_points = layer_points.getFeatures()

list_altura = []
for alturas in feature_points:
    list_altura.append(alturas['Z'])

features_selected = layer_points.selectAll()
numb_feature = layer_points.selectedFeatureCount()
layer_points.removeSelection()
sum_ = sum(list_altura)
medium_hight = sum_ / (numb_feature)

hight_variance = statistics.stdev(list_altura)

# depth
layer_all = QgsVectorLayer(valuetopoint['RESULT'])
feature_all = layer_all.getFeatures()
list_zmin = []

for z in feature_all:
    list_zmin.append(z['Z'])

depth = medium_hight - min(list_zmin)

# radius
rim = QgsVectorLayer(merge['OUTPUT'])
QgsProject.instance().addMapLayer(rim)

pointtopath2 = processing.run("qgis:pointstopath",
{'INPUT':rim,'ORDER_FIELD':'LINE_ID','GROUP_FIELD':None,'DATE_FORMAT':",'OUTPUT':'TEMPORARY_OUTPUT'})

linetopoly2 = processing.run("qgis:linetopolygons",

```

```

{'INPUT':pointtopath2['OUTPUT'],'OUTPUT':'TEMPORARY_OUTPUT'})
centroid3 = processing.run("saga:polygoncentroids", {'POLYGONS':linetopoly2['OUTPUT'],'METHOD':True,'CENTROIDS':'TEMPORARY_OUTPUT'})
layer_centroid = QgsVectorLayer(centroid3['CENTROIDS'])
feature_points = layer_points.getFeatures()
feature_centroid = layer_centroid.getFeatures()
list_radious = []
list_radious2 = []
for centroid in feature_centroid:
    geom_centroids = centroid.geometry()
for points in feature_points:
    geom_points = points.geometry()
    dist = geom_centroids.distance(geom_points)
    list_radious.append(dist)
    list_radious2.append(dist)
features_selected = layer_points.selectAll()
numb_feature = layer_points.selectedFeatureCount()
layer_points.removeSelection()
sum_ = sum(list_radious)
diameter = sum_ * 2
medium_diameter = diameter/(numb_feature)

#base and wall
i = 0
lista2 = list(map(str, range(repetition2 + 1)))
for time in range(repetition2 + 1):
    i = i + 1
    try:
        lineid2 = lista2[i]
    except IndexError:
        continue
    exp_slope = QgsExpression('"LINE_ID" = (' + lineid2 + ')')
    feature_slope = layer11.getFeatures(QgsFeatureRequest(exp_slope))
    list_zmin = []
    select_wall_list = []
    parede_id = []
    for f_slope in feature_slope:
        list_zmin.append(f_slope['Z'])
    z_max = max(list_zmin)
    z_min = min(list_zmin)
    profundidade2 = z_max - z_min

```

```

z_min_prox = z_min + ((profundidade2 / 5))
for zs in list_zmin:
    if zs >= z_min_prox:
        select_wall_list.append(zs)

base_wall = (str(min(select_wall_list)))

layer11.selectByExpression('\ "Z\ " IN (' + base_wall + ') AND \ "LINE_ID\ " = (' + lineid2 + ')',
                            QgsVectorLayer.AddToSelection)
list_data.append ((str(medium_diameter)))
list_data.append ((str(depth)))
list_data.append ((str(hight_variance)))

saveselectedbase = processing.run("native:savesselectedfeatures", {'INPUT': layer11, 'OUTPUT':
output_base})
join2 = processing.run("native:joinattributetable",
                        {'INPUT': saveselectedbase ['OUTPUT'], 'FIELD': 'LINE_ID', 'INPUT_2': merge['OUTPUT'],
'FIELD_2': 'LINE_ID',
                        'FIELDS_TO_COPY': [], 'METHOD': 1, 'DISCARD_NONMATCHING': False, 'PREFIX': "",
                        'OUTPUT': 'TEMPORARY_OUTPUT'})
xytoline2 = processing.run("shapetools:xy2line",
                            {'InputLayer': join2['OUTPUT'], 'InputCRS': QgsCoordinateReferenceSystem(crs),
'OutputCRS': QgsCoordinateReferenceSystem(crs), 'LineType': 0, 'StartUseLayerGeom':
False,
                            'StartXField': 'X', 'StartYField': 'Y', 'EndUseLayerGeom': False, 'EndXField': 'X_2',
                            'EndYField': 'Y_2', 'ShowStartPoint': True, 'ShowEndPoint': True, 'DateLineBreak': False,
                            'OutputLineLayer': output_line_slope, 'OutputPointLayer': 'TEMPORARY_OUTPUT'})

densify2 = processing.run("native:densifygeometriesgivenaninterval",
                            {'INPUT': xytoline2['OutputLineLayer'], 'INTERVAL': 300, 'OUTPUT':
'TEMPORARY_OUTPUT'})
vertices2 = processing.run("native:extractvertices", {'INPUT': densify2['OUTPUT'], 'OUTPUT':
'TEMPORARY_OUTPUT'})
valuetopoint2 = processing.run("saga:addrastervaluestopoints",
                                {'SHAPES': vertices2['OUTPUT'], 'GRIDS': slope, 'RESAMPLING': 0, 'RESULT':
'TEMPORARY_OUTPUT'})

layer12 = QgsVectorLayer(valuetopoint2['RESULT'])

layer13 = QgsVectorLayer(xytoline2['OutputLineLayer'])
QgsProject.instance().addMapLayer(layer13)

```

```

i = 0
listslope = []
lista3 = list(map(str, range(repetition3 + 1)))
for time in range(repetition3 + 1):
    i = i + 1
    # print('for1')
    # print(c)
    try:
        lineid3 = lista3[i]
    except IndexError:
        continue
    exp_lineslope = QgsExpression('\' "LINE_ID\' " = (\' + lineid3 + \') ')
    feature_lineslope = layer12.getFeatures(QgsFeatureRequest(exp_lineslope))
    for slop in feature_lineslope:
        listslope.append(slop["+slopeproj+"])
print('slope=' + (str(statistics.mean(listslope))))
print('stdv slope =' + (str(statistics.stdev(listslope))))
list_data.append ((str(statistics.mean(listslope))))
list_data.append ((str(statistics.stdev(listslope))))

#wall widht and base_diameter
x = processing.run("qgis:exportaddgeometrycolumns",
    {'INPUT':t['OutputLineLayer'],'CALC_METHOD':0,'OUTPUT':'TEMPORARY_OUTPUT'})
layer14 = x['OUTPUT']
QgsProject.instance().addMapLayer(layer14)
featparede = layer14.getFeatures()
parede = []
for f in featparede:
    parede.append(f['length'])
wall_widht = statistics.mean(parede)

base_diameter = media_diametro - (espessura_parede * 2)

# lat long
feat = QgsVectorLayer(b['CENTROIDS'])
featfeat = feat.getFeatures() # get first feature
for featurecent in featfeat:
    geo = QgsGeometry.asPoint(featurecent.geometry()) # get the geometry of the feature
    pxy = QgsPointXY(geo)

list_data.append ((str((pxy.x()))))

```

```

list_data.append ((pxy.y()))
list_data.append ((wall_widht))
list_data.append ((base_diameter))

# -----
# depth error

feature_points2 = rim.getFeatures()
list_hight = []
for hights in feature_points2:
    list_hight.append(hights['Z'])
hight_variation = statistics.stdev(list_hight)
medium_hight = statistics.mean(list_hight)
number_hight = len(list_hight)
filtro = midium_hight - hight_variation
list_points_filtro = []
for points in list_hight:
    if points >= filtro:
        list_points_filtro.append(points)
mediun_high2 = statistics.mean(list_points_filtro)
hight_variation2 = statistics.stdev(list_points_filtro)
number_hight2 = len(list_points_filtro)

rim2 = QgsVectorLayer(merge['OUTPUT'])

assignporj= processing.run("native:assignprojection",
    {'INPUT':rim2,
     'CRS':QgsCoordinateReferenceSystem(crs),'OUTPUT':'TEMPORARY_OUTPUT'})

pointtopath4 = processing.run("qgis:pointstopath",
    {'INPUT':assignporj['OUTPUT'],'ORDER_FIELD':'LINE_ID','GROUP_FIELD':None,'DATE_FORMAT':",",
     'OUTPUT':'TEMPORARY_OUTPUT'})
linetopoly4 = processing.run("qgis:linetopolygons",
    {'INPUT':pointtopath4['OUTPUT'],'OUTPUT':'TEMPORARY_OUTPUT'})
fieldcalculator5 = processing.run("qgis:fieldcalculator",

{'INPUT':linetopoly4['OUTPUT'],'FIELD_NAME':'raio','FIELD_TYPE':0,'FIELD_LENGTH':10,'FIELD_P
RECISION':3,

'NEW_FIELD':True,'FORMULA':'((length(shortest_line(centroid($geometry),boundary($geometry)))))/
2','OUTPUT':'memory'})

```

```

centroid4 = processing.run("saga:polygoncentroids",
    {'POLYGONS': fieldcalculator5['OUTPUT'], 'METHOD': True, 'CENTROIDS': 'TEMPORARY_OUTPUT'})

buffervar5 = processing.run("saga:variabledistancebuffer",
    {'SHAPES': centroid4 ['CENTROIDS'], 'DIST_FIELD': 'raio', 'DIST_SCALE': 1, 'NZONES': 1, 'DARC': 5, 'DISSOLVE': True, 'POLY_INNER': False, 'BUFFER': 'TEMPORARY_OUTPUT'})

pixels = processing.run("qgis:generatepointspixelcentroidsinsidepolygons",
    {'INPUT_RASTER': dem, 'INPUT_VECTOR': buffervar5['BUFFER'], 'OUTPUT': 'TEMPORARY_OUTPUT'})

valuetopoint5 = processing.run("saga:addrastervaluestopoints",
    {'SHAPES': pixels['OUTPUT'], 'GRIDS': dem, 'RESAMPLING': 0, 'RESULT': 'TEMPORARY_OUTPUT'})

base_layer = QgsVectorLayer(valuetopoint['RESULT'])
feature_points_base = base_layer.getFeatures()
QgsProject.instance().addMapLayer(base_layer)
list_base = []
for highs in feature_points_base:
    list_base.append((highs["+demproj+"]))
variation_base = statistics.stdev(list_base)
medium_base = statistics.mean(list_base)
number_base = len(list_base)
filtro2 = medium_base - variation_base
list_points_filtro_base = []
for points2 in list_base:
    if points2 <= filtro2:
        list_points_filtro_base.append(points2)
medium_base2 = statistics.mean(list_points_filtro_base)
variation_base2 = statistics.stdev(list_points_filtro_base)
number_base2 = len(list_points_filtro_base)

erro_hight = (math.sqrt(number_altura2 * (550 ** 2))) / number_hight2
erro_hight2 = math.sqrt((erro_alt ** 2) + hight_variation2)

erro_base = (math.sqrt(number_base2 * (550 ** 2))) / number_base2
erro_base2 = math.sqrt((erro_base ** 2) + variation_base2)

error_depth = math.sqrt((erro_alt2 ** 2) + (erro_base2 ** 2))

```



```

# diameter error
medium_radius = statistics.mean(list_radious2)
list_var= []
for dist in list_radious2:
    var = dist - medium_radius
    list_var.append(var)

square_var = []
for var in list_var:
    var_square = var**2
    square_var.append(var_square)

mean_squarevar = (sum(square_var))/ (numb_feature - 1)

error_diam = math.sqrt(mean_squarevar)

list_data.append ((str(error_depth)))
list_data.append ((str(error_diam)))

#-----

import csv
file2 = open(""+csv_file+",a",newline="")
writer = csv.writer(file2)
data= list_data2
writer.writerows(data)
file2.close()

```

Anexo 3. Tabela com dados completos

Crate	Diameter	Diamete	Dept	Dept	d/	Depth	Slope	Slope	Wall	Base	Lon	Lat.	S-C	Fresh	Area
-------	----------	---------	------	------	----	-------	-------	-------	------	------	-----	------	-----	-------	------

r	(m)	r error	h (m)	h error	D	variati on	(degree s)	variati on	width (m)	diameter (m)	g.			Crate r	
1	16405	541.00	1983	91.17	0.1 2	291.35	20.5	9.89	3787	8830	147. 8	9.2	c	x	4
2	34825	640.47	2585	55.22	0.0 7	300.40	15.4	9.04	8131	18562	149. 8	8.1	c	x	4
3	19753	276.17	2184	70.38	0.1 1	227.00	14.6	7.19	5540	8674	151. 4	10. 6	c	x	4
4	14353	419.97	1246	84.89	0.0 9	353.27	13.1	5.67	3666	7021	148. 6	12. 3	c		4
5	33187	1523.36	3335	57.09	0.1 0	389.20	19.6	11.30	7934	17319	150. 8	3.7	c	x	4
6	12786	336.64	1843	107.1 2	0.1 4	261.47	22.5	10.62	3366	6054	147. 9	5.1	c	x	4
7	11690	258.15	2441	114.6 3	0.2 1	359.94	26.8	12.26	3158	5374	146. 3	2.6	s		4
8	9295	234.23	1751	138.2 6	0.1 9	243.84	24.4	11.36	2854	3586	146. 4	1.8	s		4
9	13870	261.92	963	91.39	0.0 7	169.87	11.9	5.54	3262	7346	151. 2	8.6	c	x	4
10	29107	716.29	2591	58.57	0.0 9	607.70	12.2	9.16	7423	14262	153. 7	8.4	c	x	4
11	22140	564.05	2162	76.23	0.1 0	513.99	14.1	8.21	5166	11808	155. 1	8.4	c	x	4
12	11121	329.19	1668	126.8 3	0.1 5	185.56	18.5	10.00	3376	4369	144. 5	8.8	c	x	4
13	14126	261.74	1813	91.76	0.1 3	102.50	20.1	9.93	3214	7699	145. 5	14. 6	c	x	4
14	9703	201.49	1071	130.3 9	0.1 1	237.33	17.7	8.73	2439	4826	144. 0	10. 1	c	x	4
15	20862	455.29	1274	70.74	0.0 6	145.81	12.2	7.28	4686	11491	118. 7	14. 3	c	x	3
16	37252	735.65	2162	45.94	0.0 6	177.21	14.2	9.74	7208	22836	115. 6	15. 9	c	x	3
17	20800	358.10	1502	73.24	0.0 7	176.61	15.4	8.64	4187	12426	112. 1	16. 8	c	x	3
18	28961	316.33	2189	53.14	0.0 8	473.05	11.2	6.60	7410	14142	97.8	6.3	c	x	3
19	30960	581.05	2359	56.57	0.0 8	424.64	12.6	6.83	7588	15785	96.7	4.8	c	x	3
20	30198	764.30	2981	57.17	0.1 0	414.81	19.2	10.34	7901	14397	155. 6	11. 9	c	x	5
21	28047	310.47	3018	54.76	0.1 1	259.12	18.1	9.12	8358	11330	159. 0	-9.3	c	x	5
22	23943	639.60	2048	55.88	0.0 9	252.59	14.1	7.29	6161	11621	109. 5	11. 8	c	x	3
23	23898	411.03	1724	66.94	0.0 7	206.92	12.1	6.13	5887	12124	138. 7	20. 2	c	x	1

24	10952	125.27	1016	108.9 8	0.0 9	124.17	13.7	5.58	3045	4863	136. 7	20. 5	s	x	1
25	6588	111.72	843	163.7 7	0.1 3	108.11	15.6	6.21	1943	2703	140. 2	20. 5	s	x	1
26	10983	355.63	1525	121.2 9	0.1 4	115.25	17.3	7.45	3275	4434	138. 3	18. 9	s	x	1
27	11961	304.35	1379	106.1 6	0.1 2	85.48	16.7	7.85	3203	5555	140. 1	17. 4	c	x	1
28	9623	210.14	1258	126.9 7	0.1 3	213.31	17.4	6.49	2889	3844	144. 3	20. 1	s	x	1
29	12374	270.24	937	96.88	0.0 8	147.20	11.3	5.22	2926	6521	143. 5	23. 3	c	x	1
30	8307	239.77	921	147.5 5	0.1 1	117.82	15.2	6.75	2252	3803	145. 8	18. 9	s	x	1
31	35847	909.52	2303	50.12	0.0 6	210.03	13.2	6.33	7057	21732	132. 2	20. 3	c	x	1
32	17806	323.97	1322	72.81	0.0 7	149.33	12.5	5.50	4056	9694	130. 9	28. 4	c	x	1
33	6083	92.97	584	189.0 1	0.1 0	79.43	12.5	3.91	1698	2688	136. 6	22. 1	s	x	1
34	17570	259.79	1608	76.63	0.0 9	236.21	13.9	6.59	4573	8423	147. 1	19. 4	c	x	1
35	7643	194.36	777	152.7 2	0.1 0	271.43	14.5	4.65	1798	4048	145. 6	17. 5	s	x	1
36	16177	467.93	1200	88.45	0.0 7	219.07	13.1	7.29	3826	8524	140. 8	30. 9	c	x	1
37	14739	304.20	1198	81.51	0.0 8	105.82	10.4	6.53	4622	5494	126. 5	28. 1	c	x	1
38	21192	650.36	1928	71.62	0.0 9	156.57	13.6	6.34	5833	9525	133. 3	24. 2	c	x	1
39	12109	280.52	1254	90.89	0.1 0	160.97	14.2	6.18	3768	4572	139. 2	24. 1	s	x	1
40	29454	603.89	1316	52.92	0.0 4	123.30	9.7	5.61	6483	16488	136. 0	29. 0	c	x	1
41	11529	243.63	1333	107.6 6	0.1 2	256.11	15.4	6.30	3121	5286	140. 3	26. 2	s	x	1
42	17264	460.87	1233	80.63	0.0 7	236.62	11.4	6.18	4362	8540	121. 0	32. 1	c	x	1
43	26626	851.90	1477	54.89	0.0 6	254.88	11.8	7.31	6198	14229	100. 5	26. 5	c	x	2
44	20850	595.84	1749	79.99	0.0 8	179.89	12.1	7.11	6115	8621	100. 2	23. 0	c	x	3
45	15580	298.88	825	85.29	0.0 5	154.38	8.1	4.40	3728	8124	98.4	22. 4	c	x	3
46	8661	243.14	570	132.5 0	0.0 7	181.64	9.0	3.14	2642	3376	101. 7	18. 5	s	x	3
47	21020	643.90	1011	73.03	0.0 5	151.57	7.6	3.52	5867	9286	89.7	20. 5	c		3
48	18512	470.80	702	75.41	0.0	178.67	6.6	3.72	4897	8718	90.0	22.	c		3

					4							4			
49	10993	173.96	780	117.4 0	0.0 7	192.47	10.9	4.78	2917	5159	101. 9	16. 1	s	x	3
50	24052	654.13	1669	60.69	0.0 7	172.83	13.3	8.22	7130	9792	137. 6	5.1	c	x	4
51	14830	387.82	1800	91.93	0.1 2	221.61	19.2	9.74	3756	7318	142. 7	4.1	c	x	4
52	18915	472.70	1318	74.31	0.0 7	109.69	12.7	8.18	4099	10716	131. 2	7.9	c	x	4
53	13386	346.90	2055	101.9 7	0.1 5	204.51	21.9	11.81	3401	6585	135. 4	9.0	c	x	4
54	8632	229.17	1178	150.8 2	0.1 4	162.28	20.0	9.14	2255	4122	133. 9	9.7	s		4
55	7244	220.54	1006	149.9 9	0.1 4	138.00	18.3	7.94	1901	3443	142. 9	2.6	s		4
56	14393	355.88	2048	81.70	0.1 4	308.47	23.0	10.74	4495	5403	145. 2	-5.9	c	x	5
57	13177	329.49	1717	101.3 6	0.1 3	326.74	20.3	10.33	3372	6434	151. 6	-7.8	c	x	5
58	16342	517.74	2626	74.92	0.1 6	511.58	24.4	10.36	4188	7965	144. 4	- 10. 0	c	x	5
59	10496	409.58	1319	165.5 7	0.1 3	322.72	20.2	9.23	2674	5148	152. 4	- 11. 3	c	x	5
60	10737	233.00	2025	119.9 9	0.1 9	282.02	23.5	11.47	3138	4460	145. 4	-2.5	s		5
61	6652	139.90	1157	168.5 4	0.1 7	244.29	27.7	11.14	1431	3789	142. 9	-0.6	s	x	5
62	13045	317.46	1973	105.8 2	0.1 5	233.22	23.0	11.37	3384	6278	145. 6	0.9	c	x	5
63	24481	499.23	1690	78.95	0.0 7	395.81	13.1	5.92	6587	11308	140. 0	- 14. 2	e	x	5
64	44857	988.35	3061	43.40	0.0 7	361.01	13.2	7.68	12082	20693	139. 0	-6.4	c	x	5
65	11386	326.04	1520	137.8 8	0.1 3	178.81	19.4	9.79	2282	6822	148. 1	- 10. 9	c	x	5
66	14178	328.54	1733	98.56	0.1 2	349.67	18.8	11.86	3183	7811	139. 3	-2.2	c	x	5
67	12862	347.46	1967	106.6 7	0.1 5	488.59	23.4	11.95	3507	5848	155. 0	-1.3	c	x	5
68	6193	221.73	952	208.1 0	0.1 5	186.76	18.8	10.66	1739	2714	154. 7	-0.7	s	x	5
69	34412	646.64	2360	57.13	0.0 7	293.18	13.4	7.41	7739	18933	157. 8	4.8	c	x	4
70	12415	230.34	1032	104.8 7	0.0 8	323.91	12.2	5.55	2985	6445	160. 8	2.6	c		4

71	8984	233.14	1391	124.8 9	0.1 5	98.85	17.0	8.64	3039	2906	137. 7	16. 5	s		4
72	24134	342.50	1716	65.66	0.0 7	267.71	15.5	7.84	4847	14439	141. 6	16. 0	c	x	4
73	28690	355.82	1655	57.68	0.0 6	189.99	11.6	7.44	6535	15620	135. 1	16. 5	c	x	4
74	8653	313.95	614	155.3 1	0.0 7	203.80	10.9	4.52	2377	3899	148. 1	15. 8	s	x	4
75	14599	319.64	1675	87.73	0.1 1	218.45	17.6	8.28	3468	7663	144. 4	26. 9	c	x	1
76	12925	311.66	933	91.85	0.0 7	147.09	12.8	7.44	2662	7602	122. 8	35. 7	c	x	1
77	12593	335.96	908	87.24	0.0 7	120.20	11.7	5.31	2978	6638	129. 3	35. 0	c	x	1
78	29608	638.31	1910	54.29	0.0 6	433.10	11.0	6.99	7342	14924	146. 1	37. 7	c	x	1
79	20779	757.39	1116	73.01	0.0 5	138.25	10.7	6.37	5207	10366	128. 5	36. 5	c	x	1
80	10359	307.42	660	116.3 1	0.0 6	135.79	10.9	5.75	2853	4654	127. 1	36. 1	s		1
81	30959	715.05	902	65.42	0.0 3	156.58	6.9	5.15	7744	15471	109. 2	35. 7	c		2
82	22132	396.60	806	69.67	0.0 4	123.57	6.3	3.76	5831	10469	106. 6	36. 7	c		2
83	20886	531.24	892	68.69	0.0 4	188.56	7.1	4.51	6765	7356	111. 9	38. 7	c		2
84	15755	328.28	453	73.05	0.0 3	91.48	4.2	2.50	4388	6979	89.0	40. 3	c		2
85	18017	774.89	1248	74.71	0.0 7	195.82	11.7	6.89	4859	8298	138. 4	39. 8	c	x	1
86	13133	319.39	1095	94.80	0.0 8	171.47	12.4	5.99	3394	6345	140. 2	40. 9	c		1
87	8074	192.86	703	115.7 6	0.0 9	106.73	11.1	5.19	2104	3866	136. 2	42. 4	s	x	1
88	12756	132.68	662	90.79	0.0 5	201.92	11.3	5.56	4342	4073	124. 4	44. 6	s		1
89	36276	840.67	2453	46.10	0.0 7	371.64	11.4	6.53	9908	16460	135. 0	47. 3	c	x	1
90	12816	354.98	1293	88.10	0.1 0	186.78	13.8	7.68	3550	5716	138. 5	47. 3	c	x	1
91	22403	777.80	1364	65.78	0.0 6	250.29	10.5	6.14	6177	10049	138. 3	49. 1	c	x	1
92	17184	372.76	1422	68.84	0.0 8	358.70	11.4	5.94	4429	8326	140. 0	55. 8	c	x	1
93	11675	320.97	1175	101.4 0	0.1 0	170.05	15.2	7.49	3111	5452	144. 3	38. 6	c	x	1
94	12417	365.86	1057	128.2 1	0.0 9	190.91	13.4	6.21	3061	6295	132. 3	38. 7	c	x	1
95	7225	110.45	758	124.9	0.1	104.62	13.1	5.91	1811	3603	136.	43.	s	x	1

				1	0						1	0			
96	11135	382.11	883	109.1 5	0.0 8	137.79	9.5	5.12	3288	4560	139. 9	51. 2	s		1
97	15612	650.60	1167	89.38	0.0 7	271.17	12.2	6.29	4628	6356	134. 3	52. 7	c	x	1
98	18881	471.80	1567	71.29	0.0 8	188.45	12.5	7.87	5915	7051	173. 0	52. 4	c		1
99	13588	474.67	1067	83.16	0.0 8	282.12	12.4	7.54	3246	7096	176. 5	51. 3	c		1
100	18432	745.83	1857	72.48	0.1 0	523.73	12.7	7.15	4973	8486	179. 3	50. 8	c	x	1
101	17518	449.21	1447	66.59	0.0 8	292.51	11.5	5.93	5338	6843	180. 0	52. 2	c		1
102	19611	458.17	1634	66.15	0.0 8	382.44	13.0	8.25	4966	9679	161. 3	50. 7	c	x	1
103	33963	640.06	1807	54.32	0.0 5	341.80	11.2	7.04	9273	15416	152. 5	48. 0	c	x	1
104	40192	1251.83	2001	48.12	0.0 5	720.31	12.1	8.04	8735	22722	151. 8	44. 2	c	x	1
105	32435	813.35	1880	55.68	0.0 6	780.82	11.7	7.68	7675	17085	161. 7	44. 8	c	x	1
106	11043	269.11	1164	130.9 0	0.1 1	300.82	14.5	7.16	2938	5166	162. 8	49. 9	c	x	1
107	16029	681.00	1488	75.08	0.0 9	272.29	11.9	6.68	5043	5943	167. 8	54. 8	c	x	1
108	10723	195.47	1133	107.8 5	0.1 1	344.57	15.4	9.16	2715	5292	150. 6	43. 1	c	x	1
109	12729	284.35	844	89.68	0.0 7	176.60	11.8	7.57	2680	7369	146. 2	29. 3	c	x	1
110	11015	368.15	800	130.2 8	0.0 7	182.49	12.9	6.89	2421	6172	141. 5	30. 2	s		1
111	13591	474.73	992	89.27	0.0 7	174.42	11.4	6.28	3832	5926	145. 4	31. 7	c	x	1
112	9208	352.72	748	127.6 6	0.0 8	237.90	12.4	6.32	2398	4412	146. 2	30. 8	s		1
113	10013	683.10	1100	128.7 0	0.1 1	138.42	12.9	5.60	3104 3104	3806	142. 9	27. 0	s	x	1
114	10290	275.91	513	138.8 7	0.0 5	151.54	9.5	5.75	2299	5691	151. 6	19. 0	s		1
115	31177	447.45	2174	55.58	0.0 7	449.86	12.0	6.97	8255	14668	106. 7	9.0	c	x	3
116	8888	107.98	813	117.9 3	0.0 9	154.50	15.4	5.95	1889	5111	155. 1	6.5	s	x	4
117	16293	290.01	1122	72.21	0.0 7	222.51	9.6	5.28	3751	8792	101. 1	50. 0	c	x	2
118	24398	1016.26	839	61.39	0.0 3	116.69	5.1	2.61	7098	10202	85.7	47. 2	c		2
119	11986	124.76	434	101.4 5	0.0 4	133.38	5.7	2.61	3399	5188	91.2	37. 1	s	x	2

120	20112	463.79	1091	77.35	0.0 5	194.40	8.4	4.46	5437	9238	97.1	38. 1	c	x	2
121	34766	819.00	1792	52.99	0.0 5	167.64	9.4	5.27	7091	20584	95.9	35. 8	c	x	2
122	24949	418.53	1229	57.74	0.0 5	164.09	8.7	4.46	6340	12269	95.0	32. 7	c	x	2
123	19162	541.66	978	67.87	0.0 5	110.52	7.6	3.30	4759	9644	98.3	32. 9	c		2
124	15158	538.76	386	83.81	0.0 3	77.70	3.9	1.67	4204	6750	98.1	30. 7	c		2
125	52486	1175.18	1953	40.28	0.0 4	280.28	10.2	6.53	8750	34985	94.6	27. 9	c	x	2
126	10820	501.92	390	120.8 0	0.0 4	124.09	5.3	2.81	2833	5154	97.7	24. 3	s		3
127	13325	402.92	937	98.42	0.0 7	236.89	13.3	7.68	3071	7183	107. 1	19. 6	c	x	3
128	9347	404.32	968	136.8 1	0.1 0	151.08	14.0	7.16	2699	3950	121. 9	18. 5	s	x	1
129	13462	542.23	903	143.4 3	0.0 7	150.08	13.0	7.25	2837	7789	122. 8	15. 3	c	x	4
130	13745	107.05	967	81.93	0.0 7	302.01	11.8	5.62	3212	7320	130. 1	20. 9	c	x	1
131	43102	995.09	2368	49.74	0.0 5	475.79	13.5	6.48	7685	27732	150. 6	15. 3	c	x	4
132	8586	110.83	1329	126.8 5	0.1 5	163.54	22.5	7.00	2021	4543	148. 7	15. 4	s		4
133	14972	449.24	928	105.2 8	0.0 6	319.97	10.9	5.22	3616	7740	147. 2	16. 8	c		4
134	12469	104.71	944	97.79	0.0 8	168.87	12.1	5.22	2673	7124	140. 1	16. 4	c		4
135	13821	220.43	961	92.68	0.0 7	138.72	13.0	7.06	2905	8010	137. 7	15. 7	c	x	4
136	10757	435.71	586	122.0 2	0.0 5	77.98	8.1	3.98	3097	4563	134. 3	15. 3	s		4
137	12667	430.22	1221	119.4 5	0.1 0	199.03	15.9	8.47	3308	6051	133. 0	14. 4	c	x	4
138	9523	123.05	984	129.6 5	0.1 0	174.96	17.9	7.80	2117	5288	141. 0	13. 4	s	x	4
139	21074	466.94	1160	78.08	0.0 6	170.88	11.7	7.42	5931	9212	128. 6	14. 1	c	x	4
140	18773	330.81	1323	84.05	0.0 7	283.21	12.6	8.22	4939	8895	127. 7	14. 7	c		4
141	9688	140.94	1023	122.3 7	0.1 1	191.82	18.0	7.55	2203	5282	127. 0	13. 2	s	x	4
142	11354	320.56	1057	127.9 0	0.0 9	210.06	11.1	5.78	3594	4166	106. 8	11. 6	s	x	3
143	19582	570.34	1503	72.87	0.0 8	404.41	12.3	6.28	5524	8534	111. 3	11. 6	c	x	3
144	19342	362.73	790	74.85	0.0	164.74	7.3	4.82	4896	9549	124.	9.3	c		4

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145	11198	340.75	1113	125.4 5	0.1 0	346.90	15.6	5.85	2844	5510	120. 4	7.3	c	x	4
146	18616	419.36	1660	77.33	0.0 9	185.29	14.5	6.18	4827	8961	116. 6	7.9	c	x	3
147	10091	150.78	729	122.4 5	0.0 7	214.04	14.1	6.11	1923	6246	153. 3	12. 7	s		4
148	45789	309.91	2950	69.45	0.0 6	368.32	11.1	6.87	12347	21095	104. 0	- 13. 8	c	x	3
149	42355	310.15	2432	69.52	0.0 6	520.52	10.9	5.99	10918	20518	107. 3	- 10. 4	c	x	3
150	31604	1066.86	1894	54.76	0.0 6	232.81	12.3	5.78	9444	12717	116. 7	-7.7	c	x	3
151	42545	1226.90	2481	49.68	0.0 6	525.04	11.4	5.58	12037	18471	121. 9	-9.8	c	x	5
152	49572	735.27	3269	43.21	0.0 7	291.72	12.3	7.01	14586	20399	132. 9	- 10. 8	c	x	5
153	59414	1758.99	2882	43.63	0.0 5	366.01	11.4	6.49	15917	27581	135. 3	- 11. 0	e	x	5
154	13892	600.56	1629	89.79	0.1 2	379.41	16.5	7.03	4145	5601	136. 5	- 29. 5	s	x	5
155	15269	396.08	1519	84.30	0.1 0	285.96	16.6	7.69	3852	7565	136. 6	- 24. 2	c	x	5
156	53326	1773.98	4318	45.81	0.0 8	467.20	14.6	7.89	14225	24876	133. 4	- 35. 0	c	x	5
157	23046	493.49	2897	74.19	0.1 3	289.35	18.1	8.36	6130	10787	140. 6	- 25. 6	c	x	5
158	25895	544.82	2917	64.30	0.1 1	412.40	19.2	8.92	6486	12923	138. 9	- 19. 0	c	x	5
159	14451	385.01	1873	117.5 1	0.1 3	355.54	20.7	8.12	3315	7822	146. 4	- 17. 8	c	x	5
160	47201	915.52	3298	46.16	0.0 7	453.21	17.0	9.19	15410	16381	157. 9	- 13. 1	c	x	5
161	14365	532.67	1637	83.81	0.1 1	440.48	14.7	8.30	4377	5611	166. 7	48. 6	c	x	1
162	12447	453.63	1271	87.86	0.1 0	224.44	13.4	6.78	3351	5745	165. 6	51. 3	c	x	1
163	13759	604.79	1247	73.71	0.0 9	316.35	11.6	5.86	3665	6429	163. 1	62. 3	c	x	1

164	17562	507.64	1448	72.24	0.0 8	177.23	12.2	7.00	4900	7762	155. 6	55. 1	c		1
165	10610	276.82	1257	104.0 6	0.1 2	160.31	16.3	9.20	2500	5611	149. 3	37. 3	s	x	1
166	31583	584.01	1828	52.49	0.0 6	507.79	8.8	4.94	9432	12720	147. 8	21. 2	c	x	1
167	22588	647.27	1605	61.90	0.0 7	184.12	11.7	7.09	5940	10707	127. 5	50. 0	c	x	1
168	9870	336.27	940	107.5 4	0.1 0	266.81	10.7	4.81	2577	4716	132. 0	50. 9	s	x	1
169	19106	481.77	1861	81.23	0.1 0	258.60	15.5	9.13	5396	8313	164. 4	-7.6	c	x	5
170	12564	523.89	1101	111.6 5	0.0 9	181.11	13.3	6.16	3312	5941	162. 2	-5.4	c		5
171	15859	699.55	2084	92.59	0.1 3	336.82	18.1	8.83	4541	6778	149. 3	- 30. 0	s	x	5
172	9344	468.86	1036	142.8 4	0.1 1	297.70	20.4	10.47	2386	4572	155. 0	-9.9	c	x	5
173	5333	99.11	865	196.4 0	0.1 6	94.32	20.6	10.30	1551	2230	162. 0	- 10. 0	s		5
174	13409	450.16	1338	89.01	0.1 0	227.84	14.2	8.02	3544	6320	135. 1	1.5	c		4
175	12838	363.74	1515	96.97	0.1 2	337.85	18.1	5.67	3343	6152	141. 3	-6.0	s	x	5
176	17140	481.29	1408	84.32	0.0 8	334.03	14.2	7.22	5392	6356	137. 6	-7.3	c		5
177	12229	475.03	1821	126.9 9	0.1 5	525.16	22.3	10.45	3236	5756	149. 9	10. 5	c	x	5
178	11171	452.00	965	117.5 4	0.0 9	186.82	14.8	6.72	2690	5791	162. 9	-2.0	c	x	5
179	6357	128.65	748	180.8 3	0.1 2	148.56	17.6	9.80	1778	2800	143. 5	-2.9	s		5
180	34715	535.85	1777	53.94	0.0 5	334.53	10.0	7.32	7776	19163	97.1	12. 0	c		3
181	28153	501.09	1145	55.81	0.0 4	213.26	7.1	5.02	6556	15041	95.2	11. 1	c		3
182	17187	338.71	1255	79.94	0.0 7	221.34	11.6	6.32	4418	8352	95.5	9.3	c		3
183	31766	1035.83	1815	59.14	0.0 6	419.43	11.1	6.65	8651	14464	118. 4	5.9	c		3
184	33561	650.79	2468	51.18	0.0 7	355.28	13.8	6.52	8891	15779	131. 6	2.3	c	x	4
185	19120	719.31	1540	78.26	0.0 8	316.44	12.8	6.77	5305	8509	106. 1	3.9	c	x	3
186	14338	742.28	558	94.95	0.0 4	59.17	5.3	2.48	4689	4961	104. 2	35. 2	c		2
187	14784	479.18	1007	86.72	0.0	336.31	12.1	7.18	4117	6550	113.	30.	c	x	2

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188	14938	615.38	649	81.50	0.0 4	229.84	8.2	6.61	4186	6565	110. 3	32. 5	c		2
189	17848	795.94	1461	87.55	0.0 8	245.24	12.6	6.01	4948	7951	124. 5	-4.4	c	x	5
190	28441	847.34	2740	58.39	0.1 0	333.99	17.7	7.60	6664	15113	140. 8	- 18. 0	c	x	5
191	28528	713.31	3044	59.79	0.1 1	622.72	18.0	7.87	7857	12813	145. 8	- 14. 2	c	x	5
192	12816	357.71	1176	89.95	0.0 9	242.60	13.6	5.17	3661	5493	102. 7	-1.9	s		3
193	12182	426.38	812	92.64	0.0 7	107.45	11.7	6.41	3138	5906	122. 8	32. 9	c		1
194	30300	746.19	1679	54.37	0.0 6	319.61	8.8	4.72	8180	13939	134. 3	28. 5	c	x	1
195	22145	279.94	2010	80.24	0.0 9	589.39	15.0	6.66	5802	10540	143. 3	25. 7	c	x	1
196	49474	950.64	3855	45.64	0.0 8	465.20	10.4	5.59	16369	16736	154. 9	10. 4	c	x	4
197	20908	412.82	1118	73.91	0.0 5	211.31	10.6	5.66	4543	11821	127. 6	19. 2	c	x	1
198	17967	530.82	1363	82.53	0.0 8	258.53	15.8	9.01	4680	8608	143. 2	8.4	c		4
199	8439	304.90	606	131.2 9	0.0 7	219.68	10.6	5.73	2256	3927	142. 9	47. 4	s		1
200	7493	159.35	702	151.2 8	0.0 9	134.34	14.5	5.69	1790	3914	159. 1	4.9	s		4
201	49726	643.18	1766	44.02	0.0 4	280.99	8.0	4.67	11803	26119	130. 6	21. 9	c		1
202	16944	313.20	1284	74.36	0.0 8	133.25	12.5	6.48	4822	7301	131. 9	25. 9	c	x	1
203	6847	269.00	758	175.0 3	0.1 1	121.38	14.5	4.60	1897	3053	128. 0	25. 3	s	x	1
204	5888	198.57	986	206.3 8	0.1 7	129.30	20.9	7.88	1520	2849	139. 2	6.6	s		4
205	20930	276.99	1728	73.69	0.0 8	444.18	14.3	8.71	5963	9005	117. 4	- 28. 7	c	x	3
206	9724	196.01	940	175.0 2	0.1 0	347.17	16.6	5.59	2187	5349	115. 2	10. 1	s	x	3
207	13815	328.37	2124	87.77	0.1 5	340.39	22.0	9.45	3336	7144	146. 1	- 20. 7	c	x	5
208	29497	1365.85	3128	66.90	0.1 1	219.68	16.0	8.02	8305	12887	129. 9	- 31. 7	c	x	5
209	13934	490.69	1810	127.3 3	0.1 3	435.65	19.2	7.76	4461	5013	131. 4	- 19.	s	x	5

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210	14194	135.32	1467	85.74	0.1 0	255.98	16.2	5.64	4057	6079	138. 0	-4.1	c		5
211	22293	676.81	953	110.3 8	0.0 4	339.99	12.1	9.71	4839	12615	109. 3	13. 6	c		3
212	14104	140.97	1513	86.22	0.1 1	232.82	16.7	7.52	3555	6994	123. 3	4.0	c	x	4
213	5992	137.68	941	236.2 1	0.1 6	346.71	19.8	7.58	1773	2447	121. 9	4.5	s		4
214	60739	915.53	2695	41.73	0.0 4	352.61	9.9	5.43	17894	24952	114. 1	-4.3	c	x	3
215	6082	107.05	878	187.6 5	0.1 4	309.25	19.1	5.97	1628	2825	144. 9	- 11. 8	s	x	5
216	22755	309.91	2061	69.45	0.0 9	398.24	14.1	5.48	5531	11694	128. 4	-9.4	c	x	5
217	12226	309.95	599	118.2 0	0.0 5	157.91	9.4	4.53	3113	6000	108. 3	47. 5	s	x	2
218	6085	227.82	664	147.7 0	0.1 1	222.33	12.5	4.67	1544	2996	151. 4	49. 4	s	x	1
219	10073	357.35	445	120.2 2	0.0 4	169.69	6.4	2.71	3402	3268	101. 8	44. 8	s	x	2
220	8165	404.45	923	119.7 8	0.1 1	236.77	13.0	7.65	2507	3150	136. 3	48. 7	s	x	1
221	7644	237.20	788	137.9 8	0.1 0	97.85	13.5	6.36	1760	4124	146. 9	43. 5	s	x	1
222	8319	233.44	546	167.2 9	0.0 7	194.48	10.0	6.47	2194	3930	113. 5	6.1	s	x	3
223	10739	258.40	407	105.5 1	0.0 4	109.51	5.1	2.47	2966	4806	98.4	36. 1	s	x	2
224	10568	139.57	662	107.3 9	0.0 6	104.15	8.8	2.31	3054	4459	107. 1	- 16. 8	s	x	3
225	9481	98.13	730	117.4 6	0.0 8	144.68	10.7	3.63	2907	3667	102. 0	2.4	s	x	3
226	7913	128.20	822	149.0 8	0.1 0	151.65	13.3	4.77	2417	3079	126. 5	-4.1	s	x	5
227	10877	435.15	767	122.1 2	0.0 7	132.40	10.7	4.43	3157	4562	117. 5	- 24. 7	s	x	3
228	9384	399.05	1362	129.2 6	0.1 5	210.89	19.6	6.77	2837	3711	139. 9	- 20. 8	s	x	5
229	12089	465.28	974	107.9 8	0.0 8	307.27	13.0	4.59	3462	5164	107. 6	-2.8	s	x	3
230	8662	161.67	757	131.7 2	0.0 9	305.10	12.2	5.21	2611	3441	114. 2	-6.4	s	x	3
231	9198	211.77	1087	126.2 1	0.1 2	251.40	15.7	6.22	2781	3635	123. 2	-1.4	s	x	5
232	9305	295.47	518	133.5	0.0	146.49	7.8	2.56	2716	3873	100.	19.	s	x	3

				5	6						9	2			
233	6913	266.05	420	164.4 8	0.0 6	176.27	7.7	3.23	1876	3162	102. 7	18. 7	s	x	3
234	6617	243.99	244	196.4 5	0.0 4	109.96	5.9	2.23	1678	3262	103. 0	20. 7	s	x	3
235	8954	258.85	603	135.1 0	0.0 7	162.31	7.6	3.26	2702	3551	95.2	23. 5	s	x	3
236	10403	387.92	639	134.0 3	0.0 6	89.06	9.1	3.55	2901	4601	101. 8	21. 0	s	x	3
237	10424	391.23	814	118.7 5	0.0 8	120.21	9.4	4.42	2927	4570	101. 1	5.5	s	x	3