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Volcanic Sedimentary Rhythm Characteristics of Early Cretaceous Rhyolite Tuff in Lingshan Island, Eastern Shandong Province and its Indication to Magmatic Dynamic Process

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INTRODUCTION

01

Lingshan Island is located in the Lingshan Island Sag of the Riqingwei Basin in the interior of the Sulu orogenic belt. In the late Mesozoic, which was affected by the subduction and retreat of the Paleo-Pacific plate and the rollback of the Izenaqi plate, resulting in a huge extension. The regional lithosphere experienced thinning thermal-upwelling-stretching-detachment, and developed a large-scale continental magmatic system.

02

The volcanic-sedimentary combination strata exposed on the surface can reflect underground magmatic activities to a certain extent. For the volcanic-sedimentary rock interbed samples, the geological information is extracted for time series spectrum analysis and the existing melt dynamic evolution model in the upper crust magma chamber is combined

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01 Regional Geology

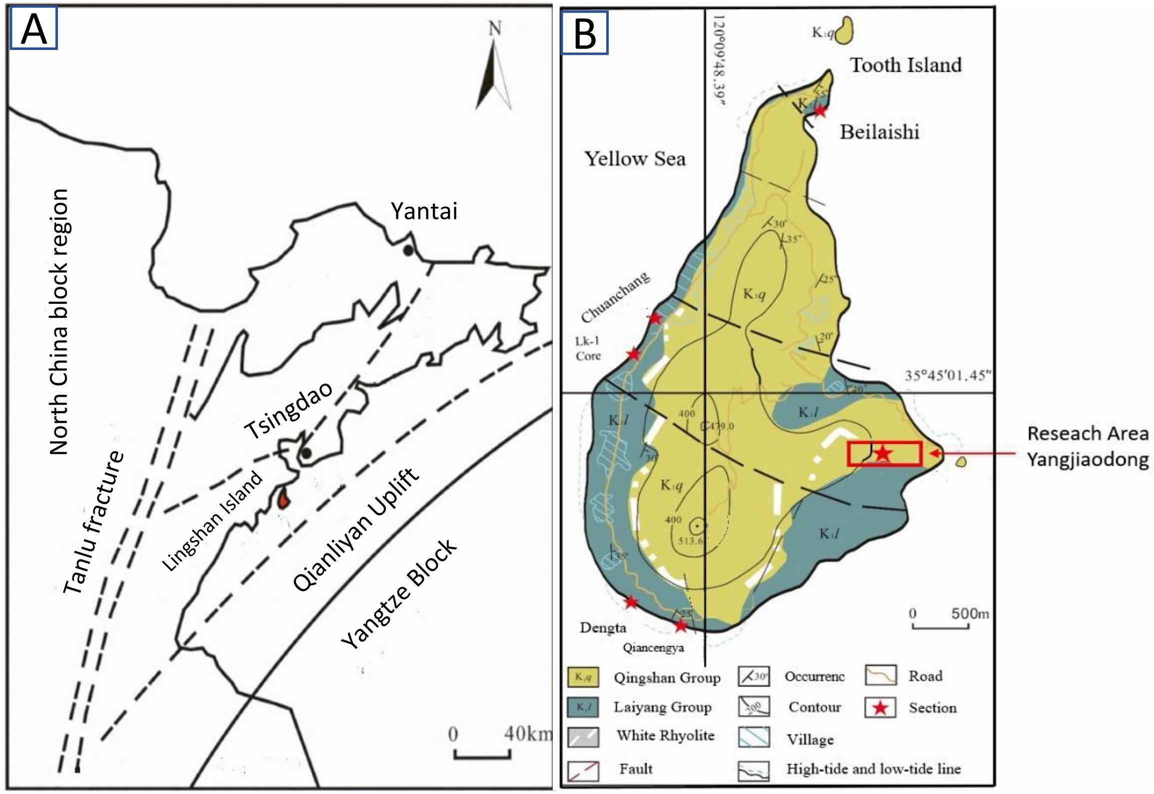


Figure.1. Geological profile and stratigraphic histogram of Lingshan Island:

(A) eastern Shandong tectonic diagram

(B)Geological survey of Lingshan Island (Modified after Shan, 2019)

Lingshan Island **is located in Lingshan Island sag in the *Riqingwei Basin* (Zhou Yaoqi, 2015), between *Qianliyan uplift* and *Jiaonan uplift*. Jiaonan uplift belongs to *Sulu Orogenic Belt*, which is formed by the collision of North China plate and *Yangtze Plate* in Triassic. The main fault strike in this area is NE-SW, which controls the tectonic units and the distribution and tendency of non-depression in the basin.**

The rhyolites on the island are widely distributed. The rhyolites and upper tuff layers in *Dengta, Yangjiaodong* and *Laohuzui* areas have good rhythmic layers, which are mainly composed of light tuff and dark normal sedimentary sandy mudstone.

Sample Position

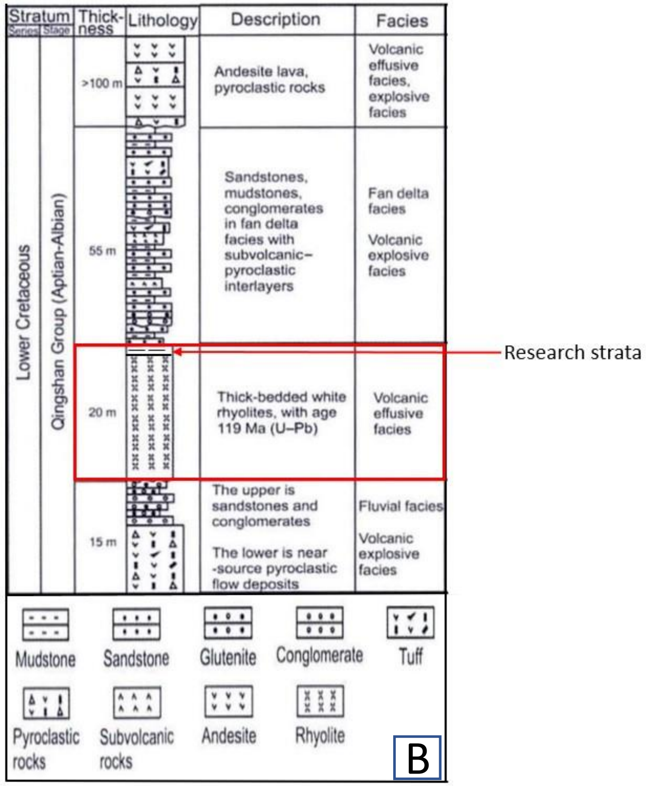


Fig. 2. Yangjiaodong samples of Lingshan Island

(A)Field Photos of Yangjiaodong Profile in Lingshan Island (B)Profile of the Qingshan Group Strata in the Yangjiaodong Section of Lingshan Island, Shandong Province (Modified after Peng, 2017)

The Yangjiaodong area develops a complete volcanic-sedimentary stratum of the Qingshan Group. From bottom to top, the volcanic clastic rocks and terrigenous clastic rock deposits, rhyolite, terrigenous clastic rocks with multiple sets of volcanic debris flow deposits and volcanic lava layers are developed. The strata are tuff interbeds in the upper part of the second-thick white rhyolite layer.

02

Geochemical Characteristics

Petrographical Characteristics

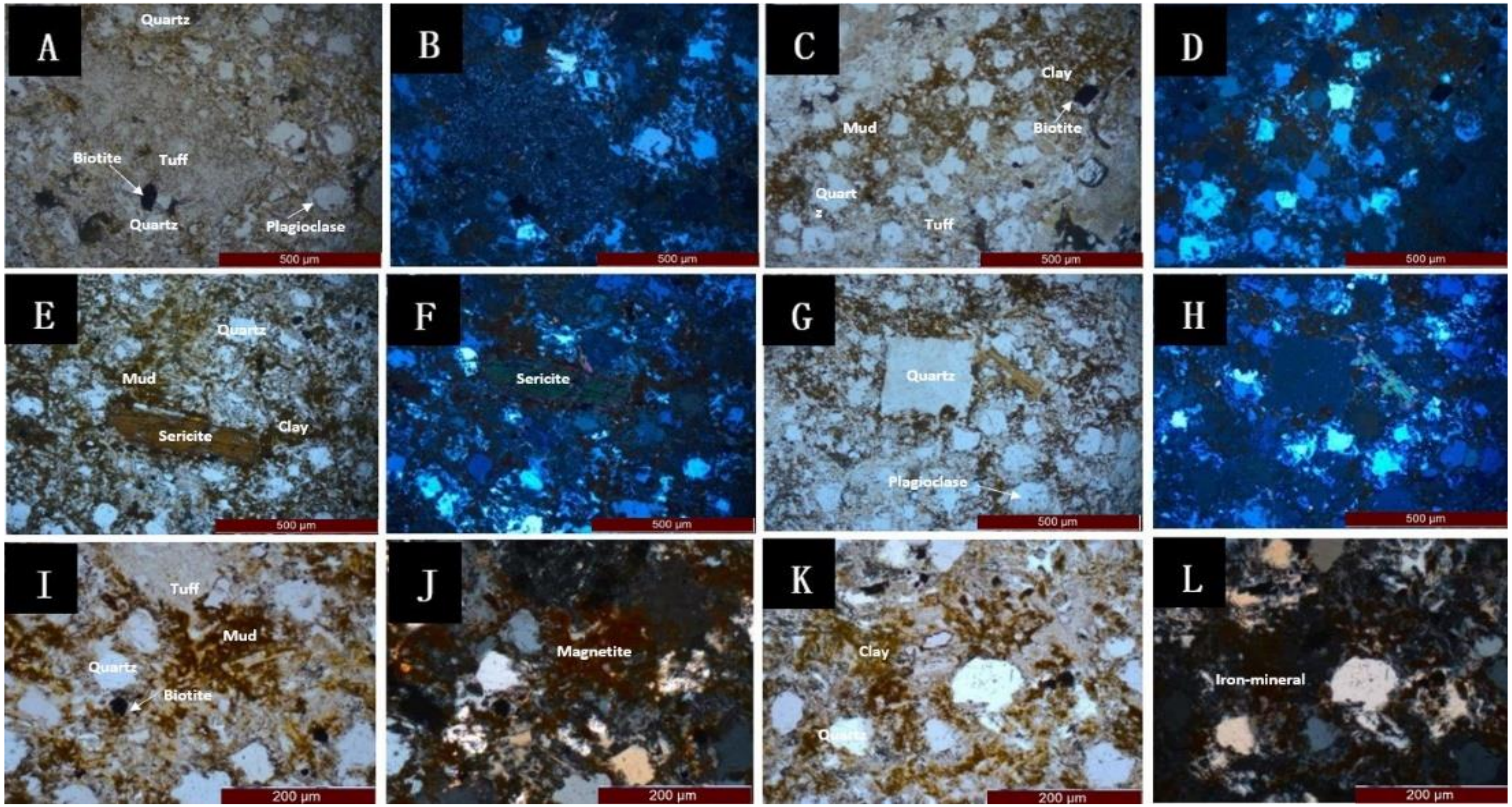
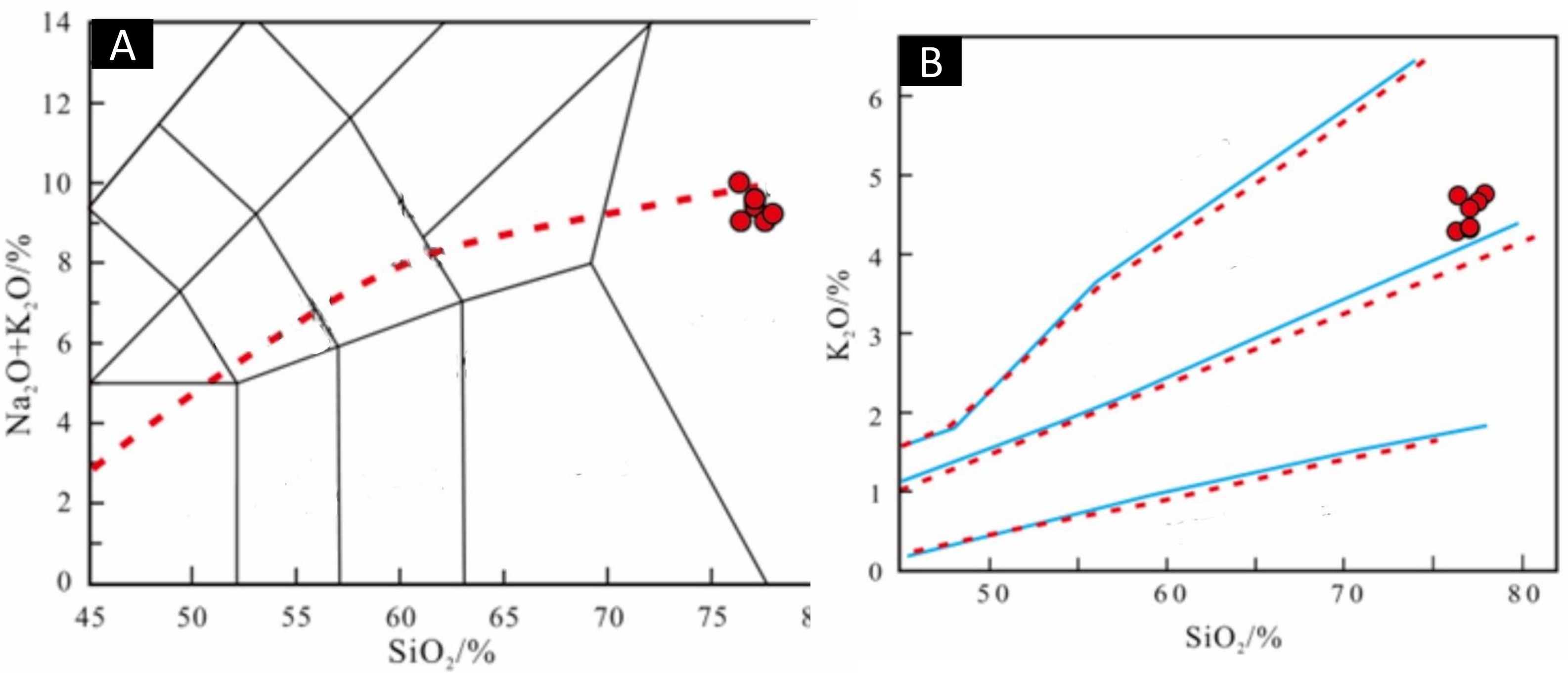


Fig.3. Petrography characteristics of rock sample in Lingshan Island

(A: single polarizer B: orthogonal polarizer; C: single polarizer D: orthogonal polarizer; E: 5x single polarizer F: orthogonal polarizer; G: single polarizer H: orthogonal polarizer; I: single polarizer J: orthogonal polarizer; K: single polarizer L: orthogonal polarizer)

The rhyolitic tuff has the characteristics of rich potassium, rich alkali, poor calcium and low titanium. Overall belongs to weak peraluminous high potassium calcium rock series. The total rare earth content is low, the distribution of light and heavy rare earth is weak, and the Eu is significantly negative anomaly, indicating that it is formed in the extensional decompression background.



C

SiO_2	75. 46	75. 24	75. 82	75. 58	75. 31	75. 74	75. 41	75. 45	75. 47
TiO_2	0. 08	0. 08	0. 08	0. 09	0. 08	0. 08	0. 09	0. 09	0. 09
Al_2O_3	13. 18	13. 15	13. 21	13. 20	13. 17	13. 17	13. 24	13. 23	13. 20
$Fe_2O_3^T$	0. 80	0. 83	0. 80	0. 81	0. 79	0. 82	0. 79	0. 81	0. 83
MnO	0. 06	0. 05	0. 06	0. 06	0. 06	0. 06	0. 06	0. 06	0. 06
MgO	0. 15	0. 13	0. 14	0. 14	0. 12	0. 14	0. 14	0. 14	0. 13
CaO	0. 19	0. 46	0. 11	0. 10	0. 33	0. 10	0. 30	0. 37	0. 22
Na_2O	4. 61	4. 73	4. 65	4. 63	4. 68	4. 58	4. 71	4. 87	4. 68
K_2O	4. 38	4. 10	4. 34	4. 42	4. 29	4. 37	4. 22	4. 19	4. 20
P_2O_5	0. 07	0. 15	0. 02	0. 01	0. 01	0. 01	0. 01	0. 01	0. 01
LOI	0. 86	0. 99	0. 82	0. 93	1. 07	0. 92	0. 99	1. 01	0. 94
Total	99. 84	99. 91	100. 05	99. 97	99. 91	99. 99	99. 96	100. 23	99. 83
A/CNK	1. 04	1. 01	1. 05	1. 05	1. 02	1. 06	1. 03	1. 00	1. 04
$Mg^\#$	30. 4	26. 7	29. 0	28. 7	26. 1	28. 5	29. 2	28. 7	26. 7
σ	2. 49	2. 42	2. 46	2. 51	2. 49	2. 45	2. 46	2. 53	2. 43
K_2O+Na_2O	8. 99	8. 83	8. 99	9. 05	8. 97	8. 95	8. 93	9. 06	8. 88
K_2O/Na_2O	0. 63	0. 57	0. 61	0. 63	0. 60	0. 63	0. 59	0. 57	0. 59

Fig 4 Geochemical characteristics of rhyolitic tuff in Lingshan Island (Zhang Shukai, 2019)
(A : TAS Diagram B : SiO_2-K_2O Diagram C : Datasheet for Major Elements)

Results of Rhyolitic Tuff Dating

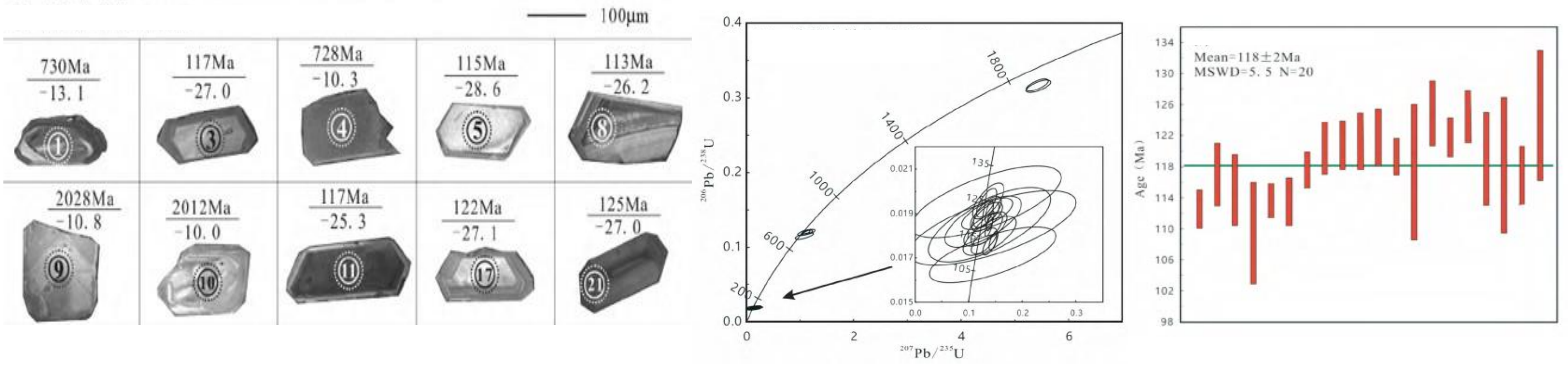


Fig. 5. CL image characteristics of representative zircons from rhyolitic tuff samples in Lingshan Island, LA-ICP-MS zircon U-Pb age harmonic map and weighted average age (Ao Wenhao, 2018)

The dating results show that the formation age of rhyolite is 118 ± 2 Ma, which belongs to the product of Early Cretaceous magmatic activity.

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03

Dynamic Evolution Model

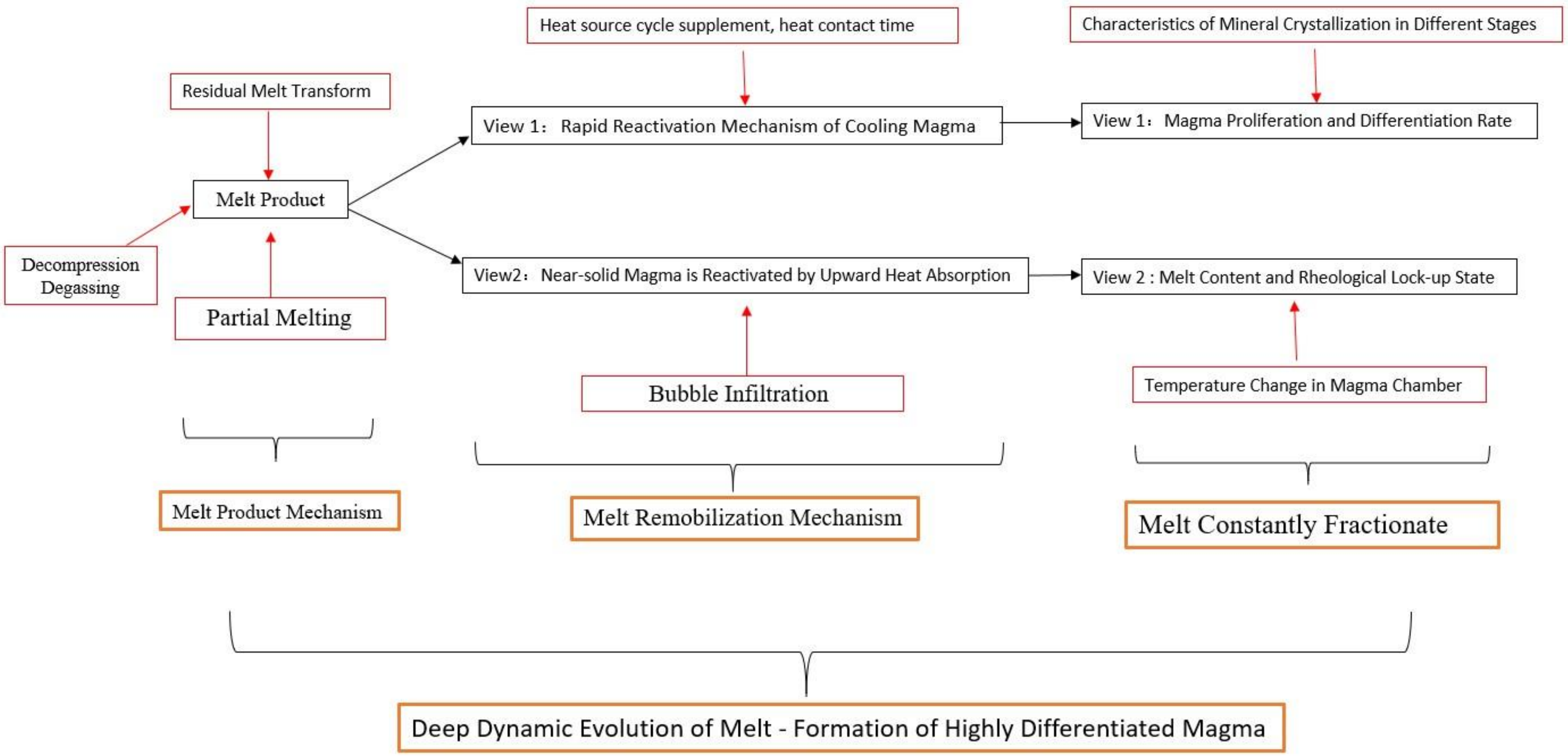


Fig6. Mechanism Diagram of Melt Generation - Activation - Change

Summary

The melt is the driving force of magma activation. The melt itself undergoes three period of generation, activation and self-change, finally the magma rises to the near-surface magma chamber for short storage, and intermittent eruption occurs when the temperature and pressure conditions are satisfied

First of all, there are two viewpoints on the generation mechanism of melt : the transformation of pre-crystal and the formation of melt by partial crystallization

Secondly, the activation mechanism of melt has two mechanisms : the thermal contact type with periodic supplement of heat source and the activation of near-solid magma by upward heat absorption through gas permeation

Finally, the relative size of the melt content and the rheological lock-up window (melt content : 30wt % -50wt %, temperature : 750 ℃ -800 ℃) makes the melt migrate to the near surface to wait for eruption

04 Establishment of Volcanic Cycles

Preliminary Data Processing

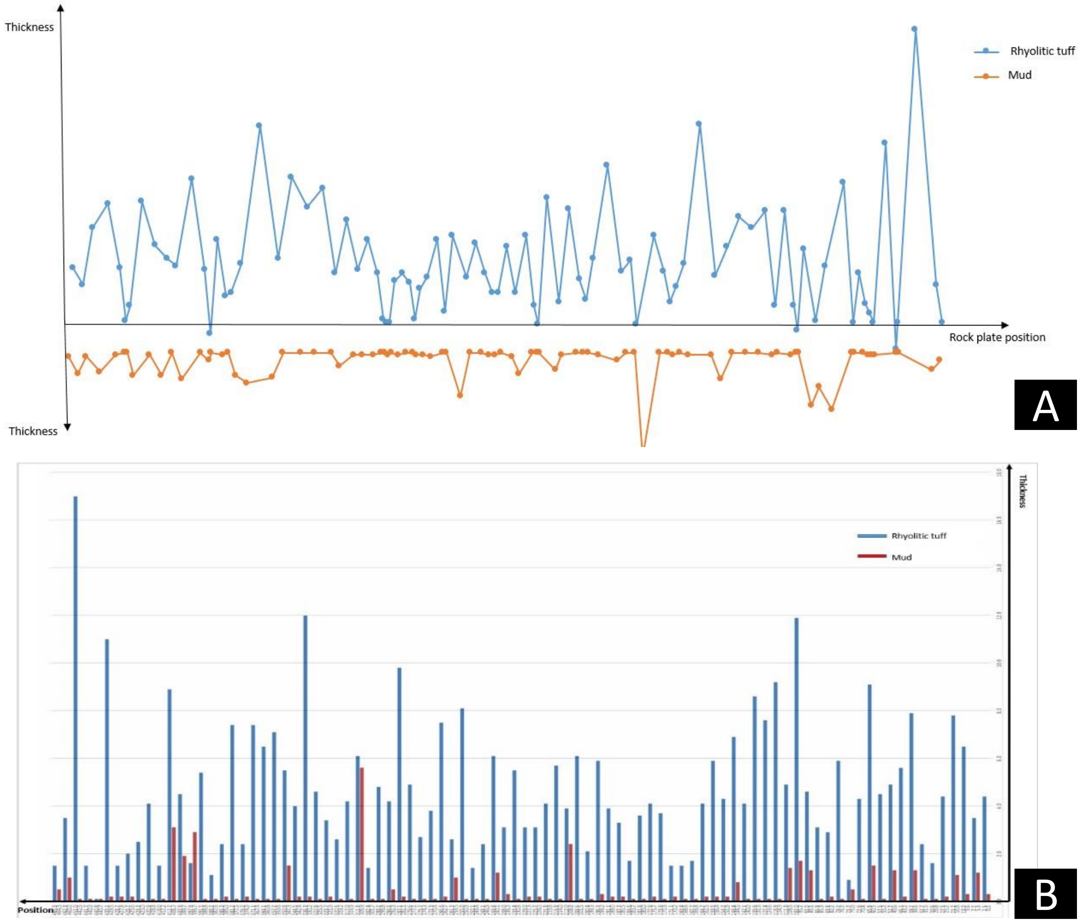


Figure 7. Digital map of rock sample in Lingshan Island

(A) lithologic broken line statistical figure

(B) lithologic histogram (mudstone: red; rhyolite tuff: blue)

The thickness statistics of rhyolitic tuff-sandstone-mudstone were carried out on the obviously rhythmic slab. Selecting parameter such as the deposition rate of volcanic back-arc basin (6.5 m / Ma) with insufficient supply of material source and the compaction factor of mudstone (0.3), the time span of sand-mudstone on the slab was calculated to be 2.24Ma. The thickness of tuff rhyolite represents the eruption scale. The sand-mud stratum represents the intermittent time of volcanism.

Methodology

Data processing steps : (Software : ACYCLE, MATLAB, EXCEL)

1. Layout data, imported into TXT in specified format

2. Processing raw data : sorting, deleting nulls, averaging

3. Data must be interpolated to a uniform sampling interval

4. Detrending the data and extracting the LOWESS curve for spectrum analysis (MTM)

5. Power spectrum per thousand years obtained

6. Calculating the period, using the formula Period = 1/Frequency

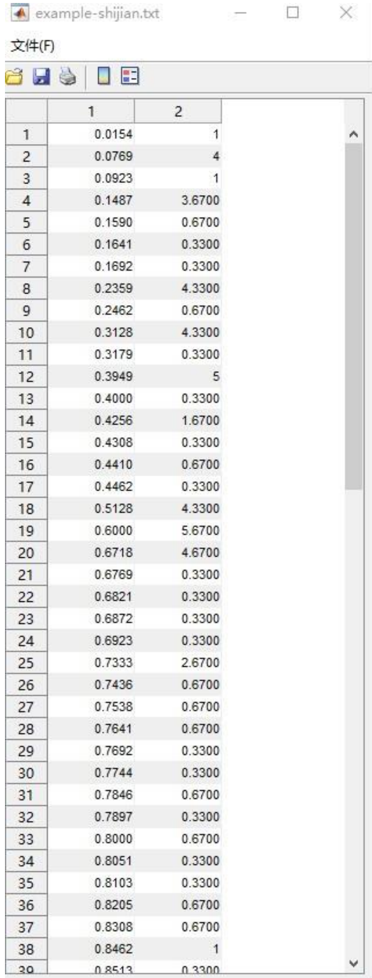
7. Scale Data Using the same way to analysis

8. According to the separated data, the corresponding scale map and event map are compared and analyzed to obtain the scale-period coupling results of magma chamber.

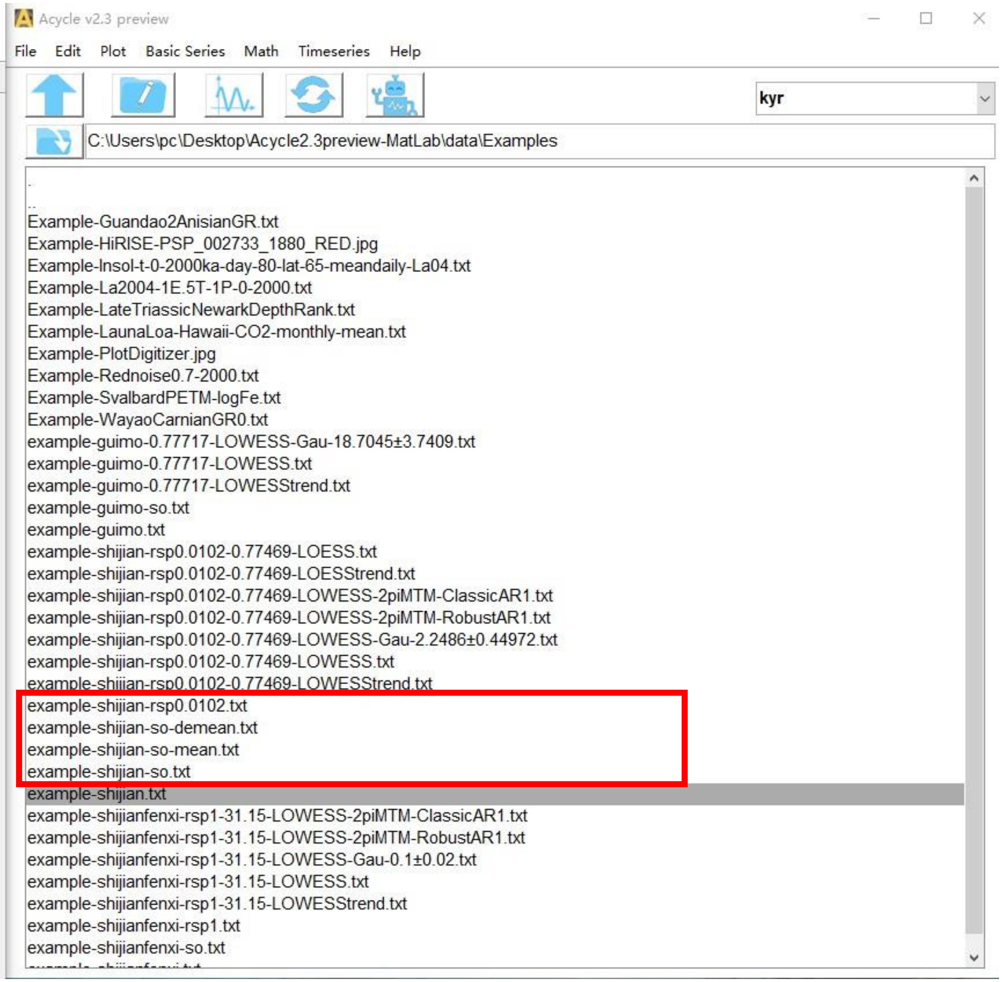
9. A particular temperature and pressure condition in magma chamber theory matches, erupting above the horizontal line, intermittent below, mapping

10. A map represents a magma chamber that ultimately explains the characteristics of volcanic activity in the study area

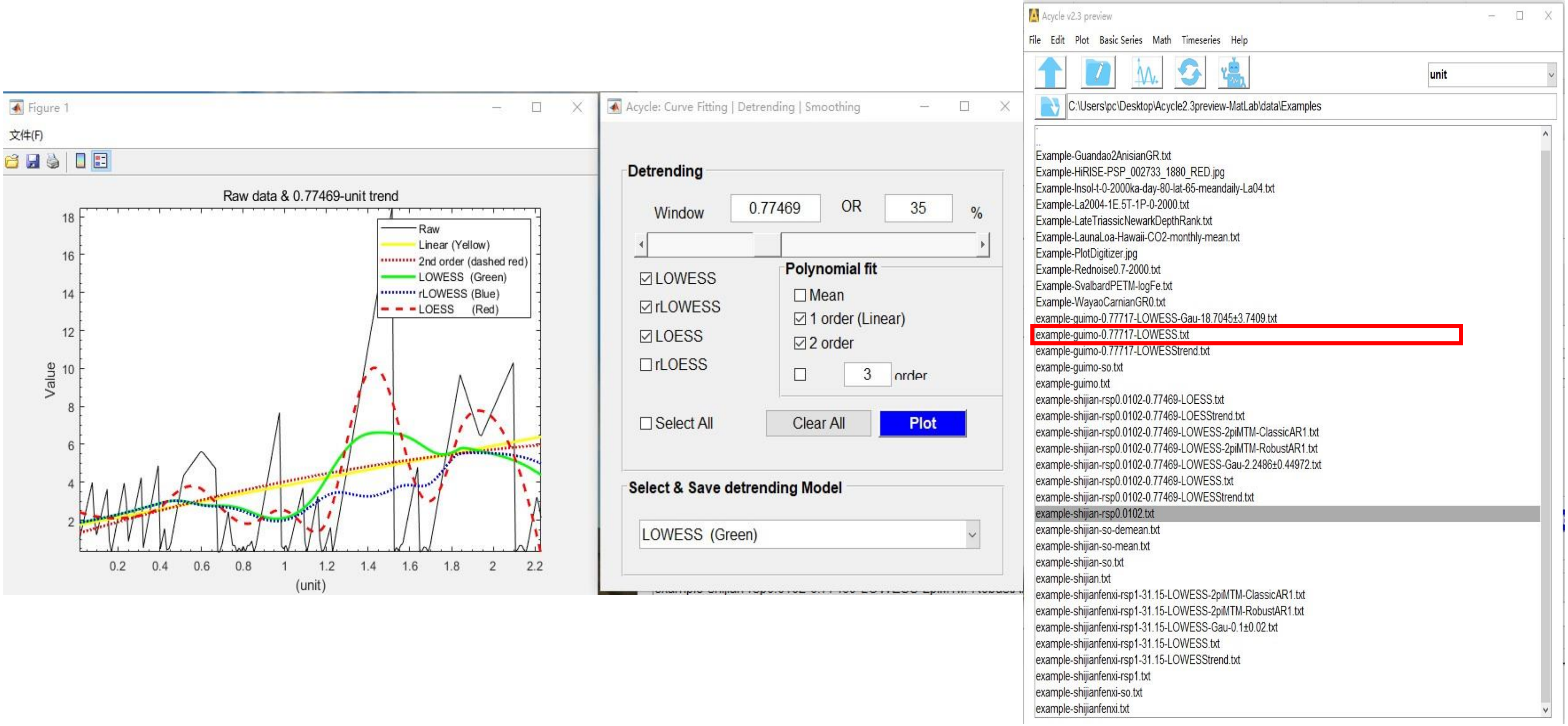
Step 1 : The original data are converted into txt format according to the cumulative time-sandstone thickness sequence. Interpolation once in the math drop-down box (getting uniform sampling space) and detrending for processed data



	1	2
1	0.0154	1
2	0.0769	4
3	0.0923	1
4	0.1487	3.6700
5	0.1590	0.6700
6	0.1641	0.3300
7	0.1692	0.3300
8	0.2359	4.3300
9	0.2462	0.6700
10	0.3128	4.3300
11	0.3179	0.3300
12	0.3949	5
13	0.4000	0.3300
14	0.4256	1.6700
15	0.4308	0.3300
16	0.4410	0.6700
17	0.4462	0.3300
18	0.5128	4.3300
19	0.6000	5.6700
20	0.6718	4.6700
21	0.6769	0.3300
22	0.6821	0.3300
23	0.6872	0.3300
24	0.6923	0.3300
25	0.7333	2.6700
26	0.7436	0.6700
27	0.7538	0.6700
28	0.7641	0.6700
29	0.7692	0.3300
30	0.7744	0.3300
31	0.7846	0.6700
32	0.7897	0.3300
33	0.8000	0.6700
34	0.8051	0.3300
35	0.8103	0.3300
36	0.8205	0.6700
37	0.8308	0.6700
38	0.8462	1
39	0.8513	0.3300



Step 2 : Use smoothing in time series and save LOWESS data to get filtered data



Step 3 :Using the Lowess Data to get to Power Diagram

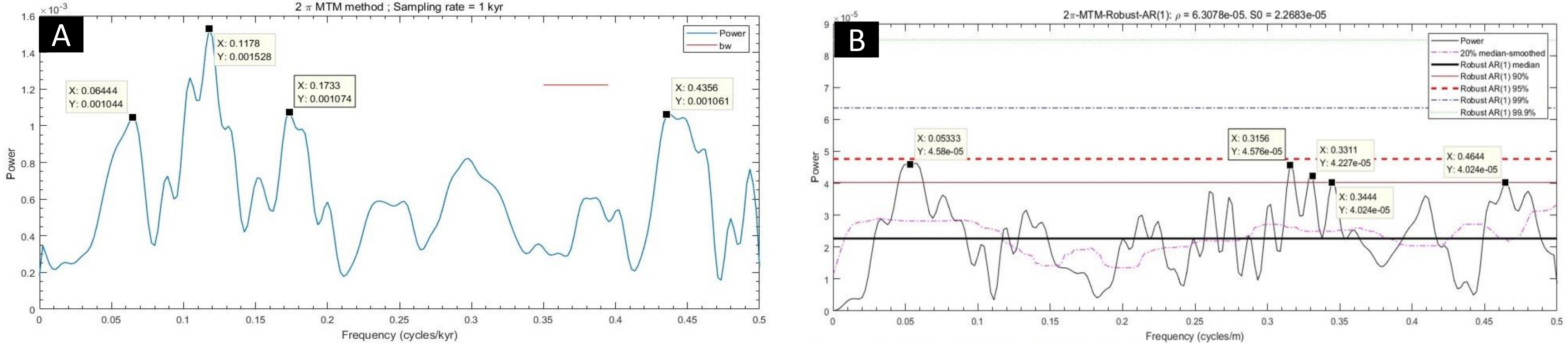
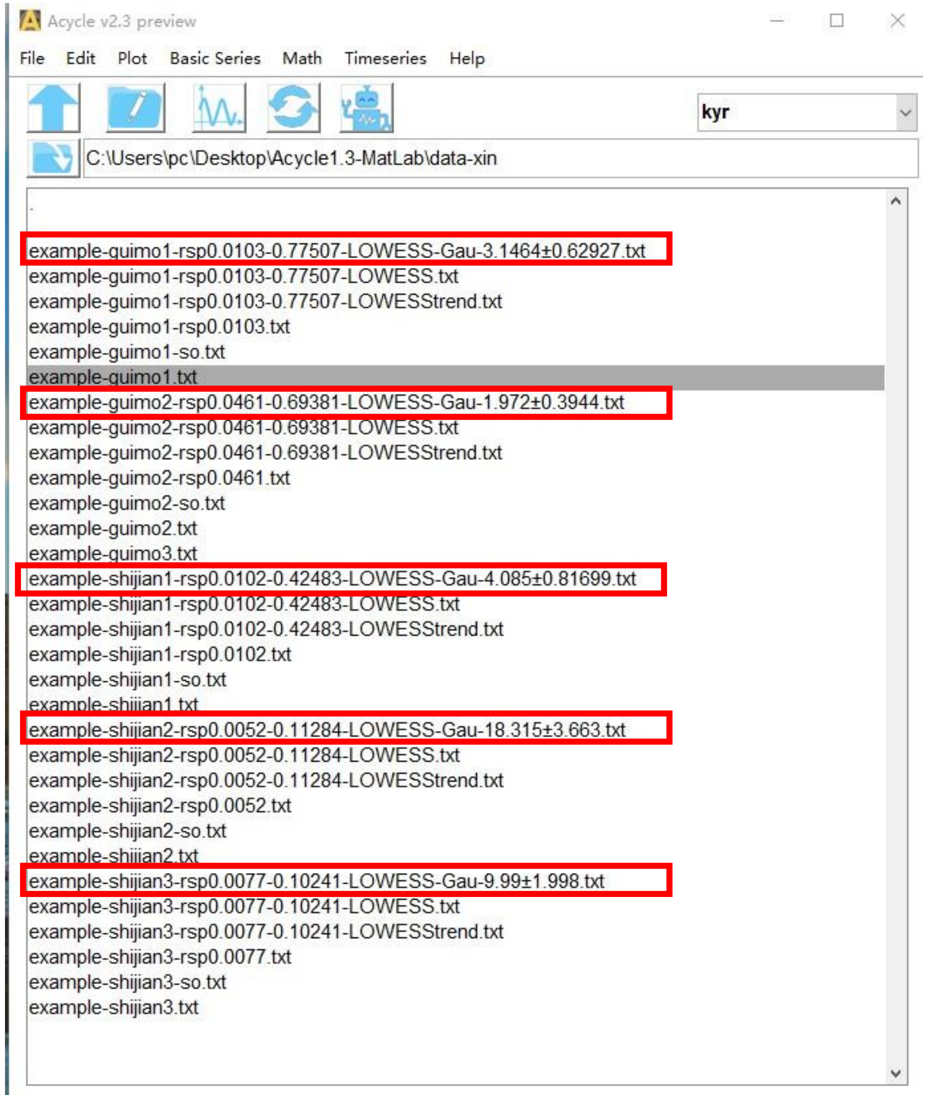


Fig.5. Acycle power periodogram (A) Time analysis (B)Scale analysis

Four cycles are calculated: 2.296kyr, 5.78kyr, 8.475kyr, 15.625kyr, the results show that the probability of these four cycles is the highest in the time range shown by the rock sample. As for the calculation of scale, the two points (0.3156 and 0.3311) which are closer to the numerical value are combined to obtain an average of four scales: 2.17 m, 2.94 m, 3.12 m and 18.87 m, which indicates that these four eruption scales exist within the thickness recorded by rock samples.



Step 4 : According to several groups of data separated by cycle, The filtered waveform is superimposed in Coreldraw

Time Series Analysis (Crater Number Determination)

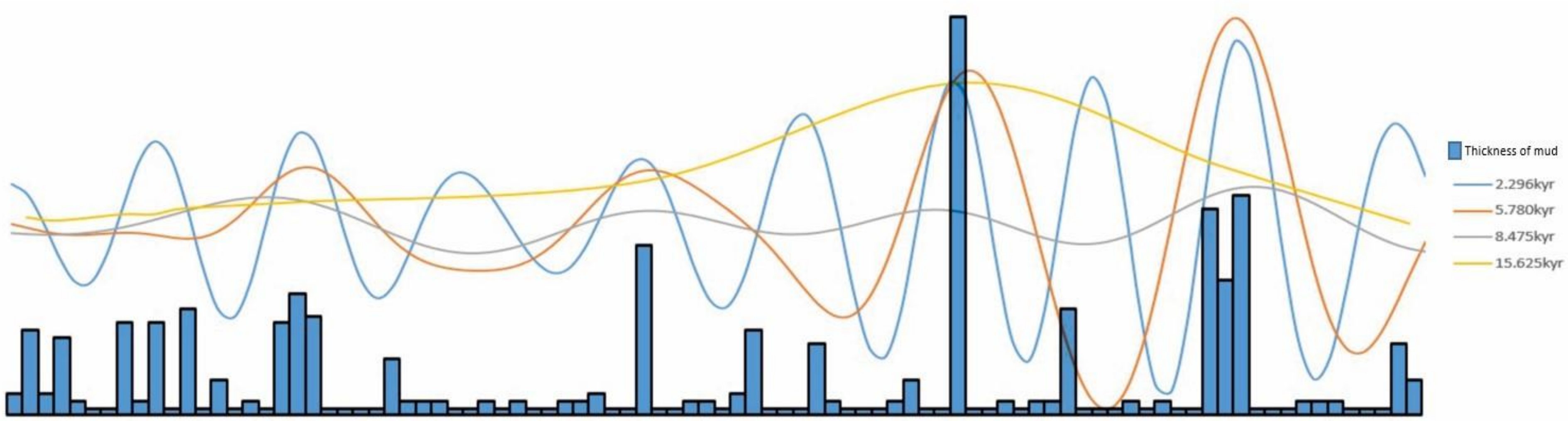


Fig.8. Periodic filtering results with interval matching plots

The minimum cycle (2.296kyr) has gone through nine cycles, which is basically consistent with the total time span of the collected samples of 2.24Ma. The corresponding 5.78kyr has roughly four cycles, 8.475kyr has about three cycles, and 15.625kyr has only one cycle.

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05 Evolution Mode and Period Coupling

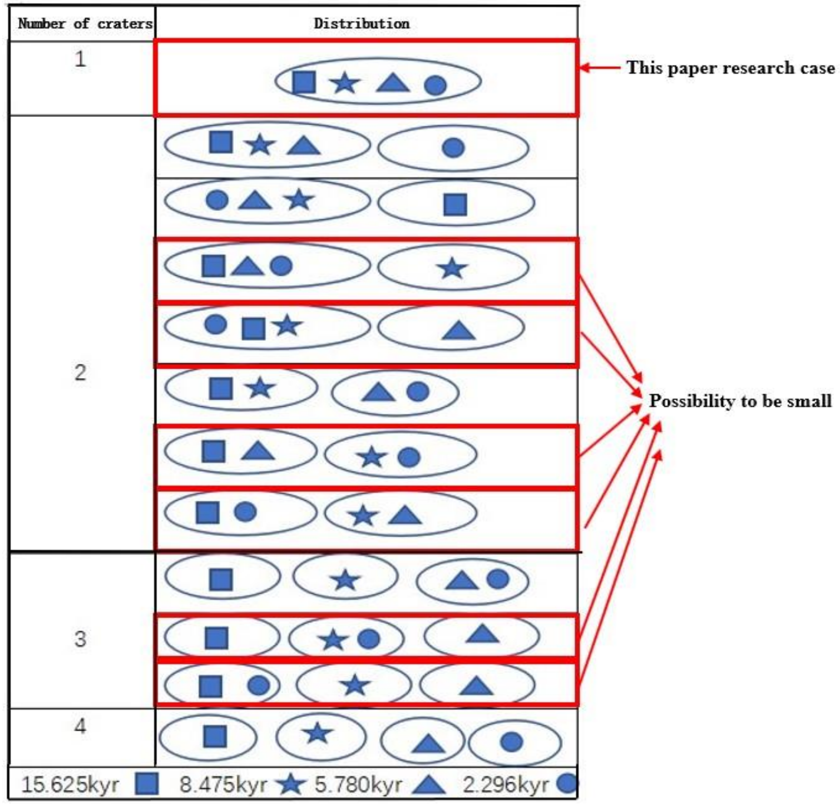


Table 1 Distribution of the number of volcanic craters

The first case: there is only one magma chamber, with the time goes by, the temperature and pressure conditions in the magma chamber will continue to change. The previous magma eruption will affect the next volcanic activity. The previous eruption can block the magma channel and may also create conditions for the next eruption.

The second case: there are two magma chambers underground, because there are four cycles, if each magma chamber erupts in two cycles, there are five distribution modes; if the magma chamber model has four combinations according to one and three distributions.

The third case: there are three magma chambers underground, one is erupted in two ways, there are four modes.

The fourth case: four periods represent four magma chambers, each magma chamber erupts according to one period.

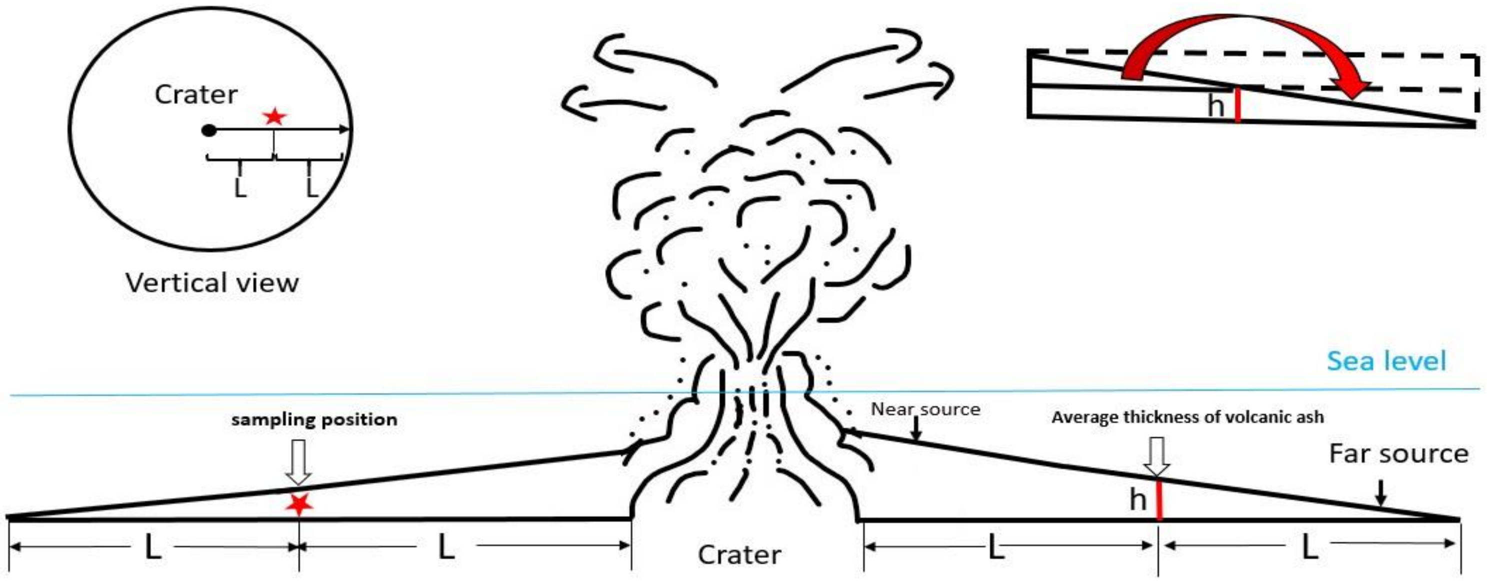


Figure.9. Volcanic Eruption Pattern Map of Study Area

Volcano erupts many volcanic materials outward every time. The thickness of volcanic ash decreased from near to far after falling. That is to say, an approximately circular region with a radius of about twice the distance (2L) is formed near the sampling point. The reason for this assumption is that the eruption material is volcanic overflow tuff facies, and coexists with rhyolite, so the distance from the crater will not be too far from the sampling point.

Matching the four scale-time diagram with the melt activated rheological lock-up window to predict the number of magma chambers near surface

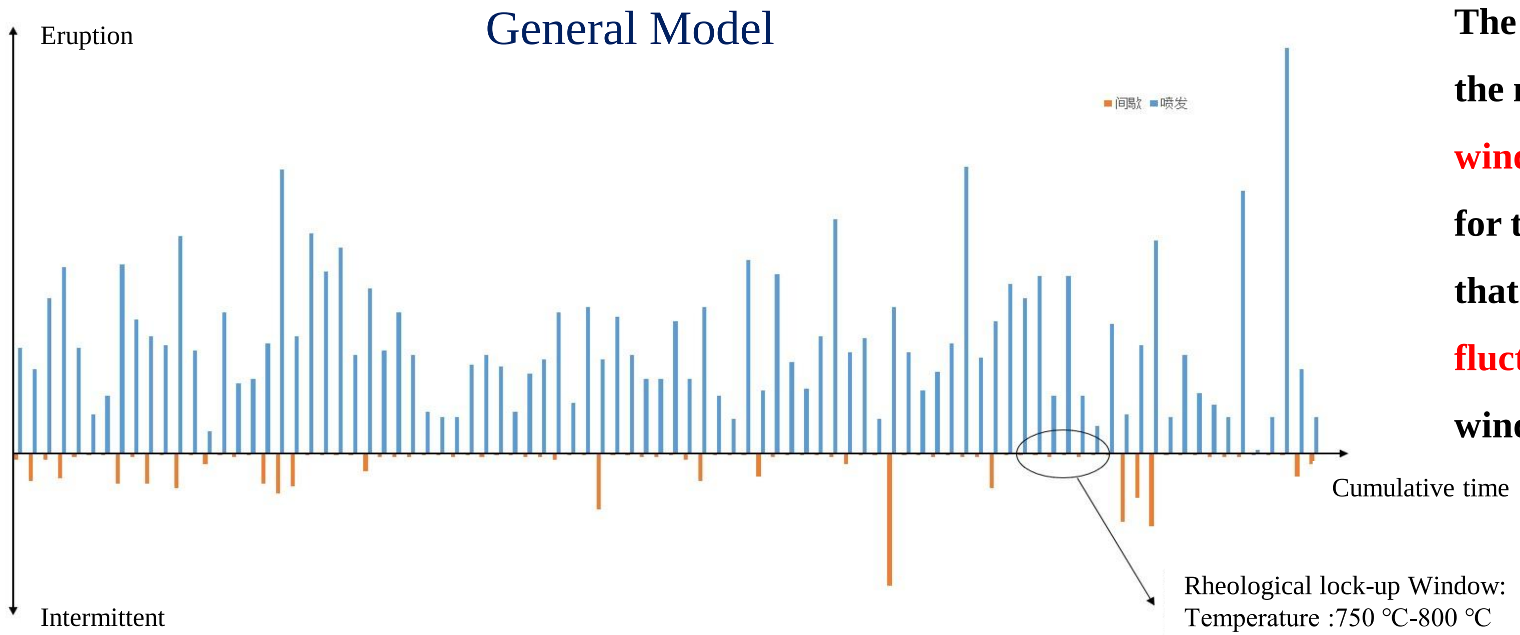
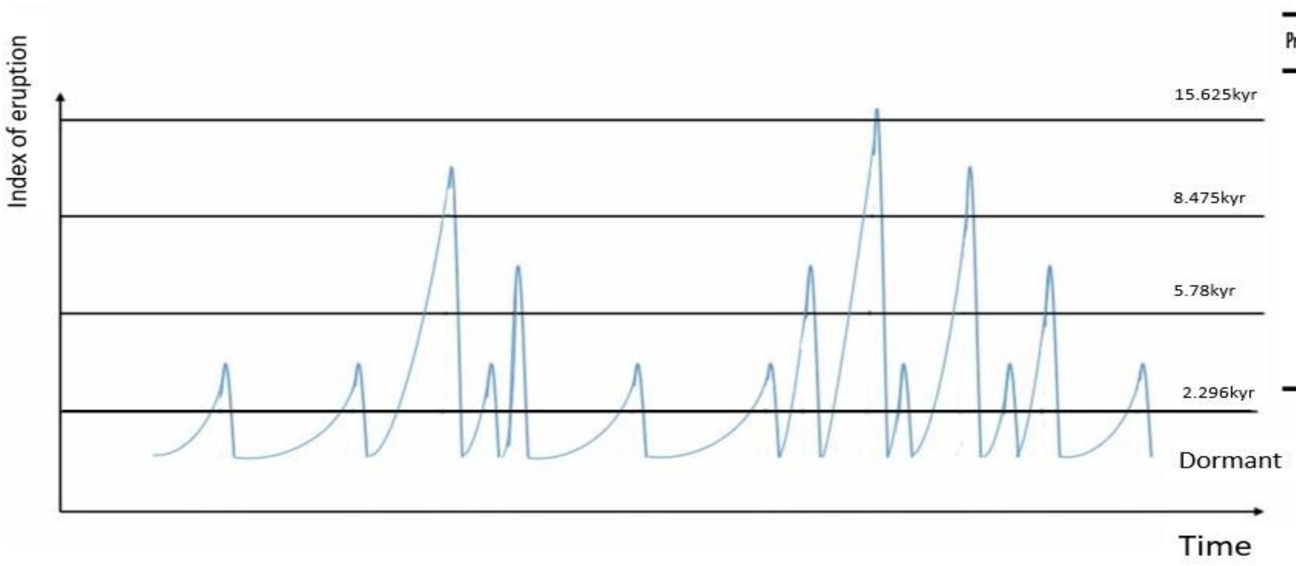


Fig 10. Volcanic Eruption-Intermittent Mode Coupling Diagram

Rheological lock-up Window:
Temperature :750 ℃-800 ℃
Water content:2wt%-305wt%
Pressure:150Mpa-200Mpa
Melt content:30%vol-50%vol
Crystallinity:0.4-0.6

The magma erupts depends on whether the melt in the magma chamber reach the rheological lock-up window (magma crystallinity > 0.6). The premise for the formation of highly differentiated granite is that the temperature and pressure conditions fluctuate up and down the rheological locking-up window repeatedly.

06 Conclusion



Pressure/MPA	Melt/%vol	Crystallinity/1	Eruption scale/M	Temperature/°C	Watewr/wt%
200	50	0.6	18.87	800	3.5
160	40	0.5	3.12	770	3
155	35	0.45	2.94	760	2.5
150	30	0.4	2.17	750	2

Fig.11.Pattern map of volcanic eruption in Yangjiaodong area of Lingshan Island

The farther the magma chamber is from the surface, the higher the temperature and pressure conditions are required. Based on this theory, the rheological lock-up points of four eruption modes are determined. The form of volcanic eruption in the study area shows the characteristics of pulse change, reflecting the periodicity and cyclicity of volcanic eruptions.

Hypothesis of Magma Chamber Depth – Size by Volcano Near Surface

Eruption

↑

Melt Enters Magma Storage for Eruption

↑

Secondary Migration of Melt : Continuous Differentiation During the Period and Floating around the Rheological Lock-up Window

↑

Melt Activation Process : Periodic Supplement of Heat Source and Mixing of Magma with Different Components through Gas Permeation

↑

Melt First Migration : Energy Reduction

↑

Melt Production : Water Injection, Decompression Degassing is External Condition

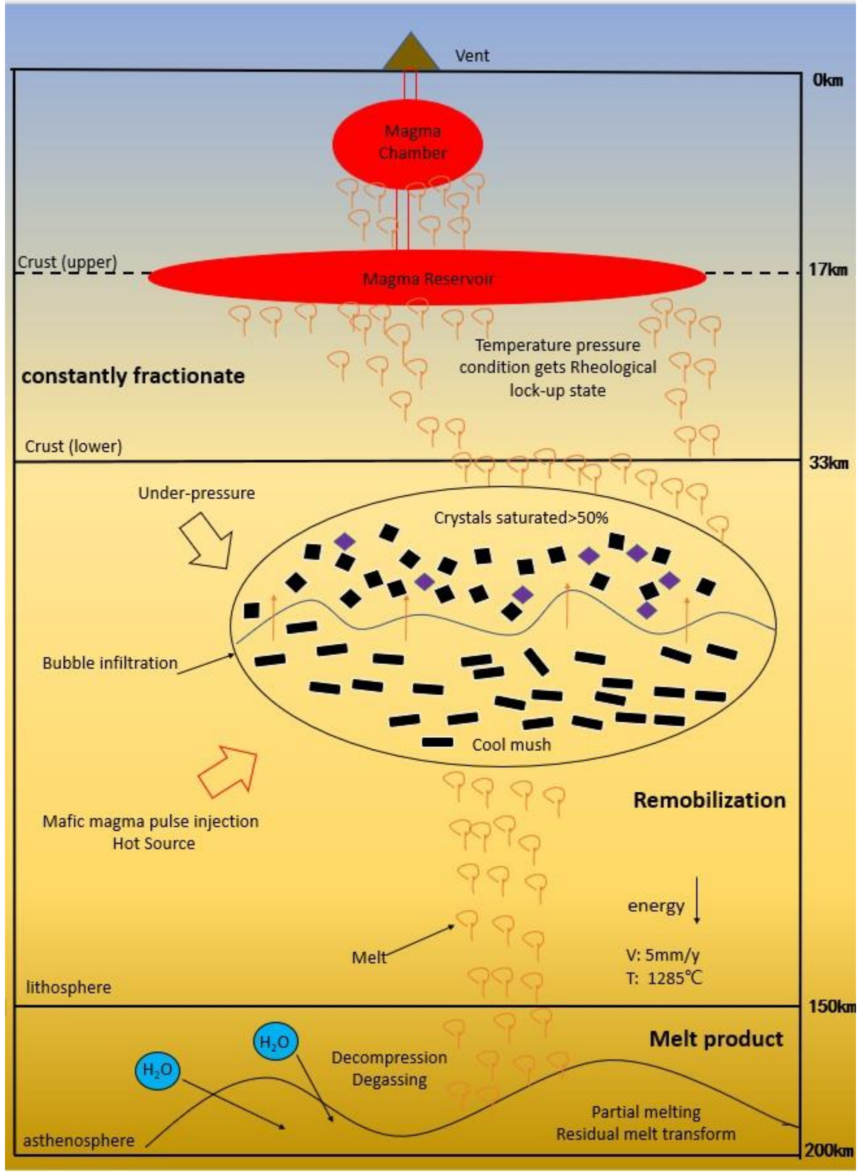


Fig. 12. Melt Evolution Process and Near-Surface Magma Chamber Model

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Thanks for listening

Question answering time