

X線マイクロモグラフィーを用いた 星周ダストアグリゲイト模擬物質の解析

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1) 阪大・理 2) TU Braunschweig,
3) SPring-8/JASRI, 4) GSJ/AIST

Introduction

固体微粒子(ダスト)の付着成長($\sim \mu\text{m}$)
→ ダスタグリゲイト



微惑星の形成 ($> \text{km}$)

原始惑星系円盤内でのダスト
アグリゲイトの構造の変化



protoplanetary disk



Planet formation



微惑星形成・進化過程を理解するためには、ダストアグリゲイトの構造を調べるのが重要。

Previous studies

- Numerical simulation

ダストアグリゲーションの過程や、その3次元構造の変化を明らかにした。

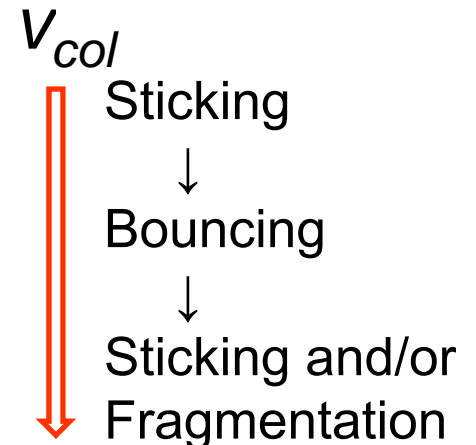
BCCA (e.g., Wada et al. 2007, 2008; Suyama et al. 2008)

BPCA (e.g., Wada et al., 2008,2009)

- Experiments

ダストの直接合体成長に関して、その衝突速度とアグリゲイトの振る舞いについて明らかにした。

(e.g., Blum and Wurm, 2008, Güttler et al., 2010)



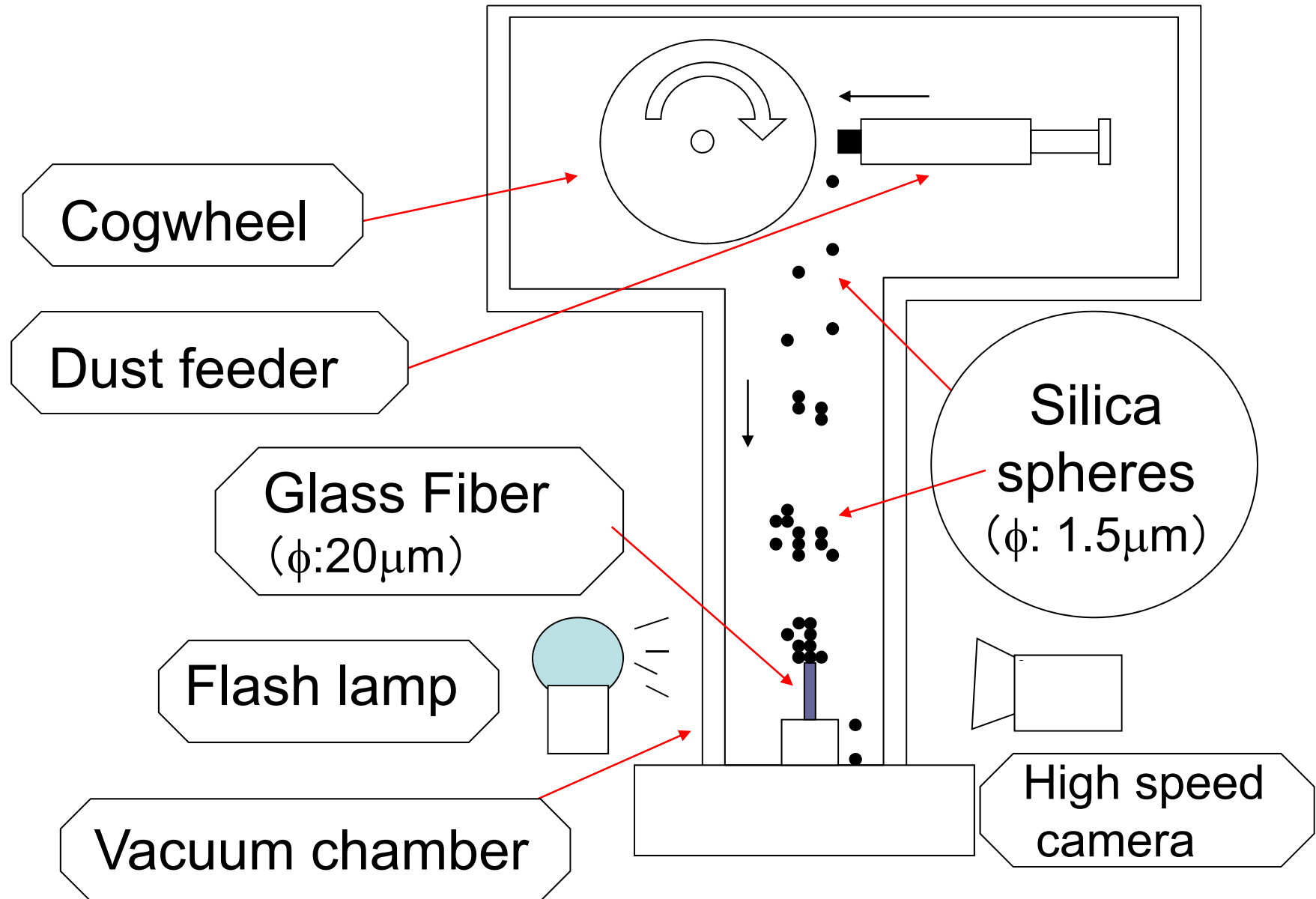
しかし、アグリゲイトの詳細な三次元構造については未だ実験的に明らかにされていない。

研究目的

- ダストアグリゲイトの3次元構造を実験的に明らかにする。

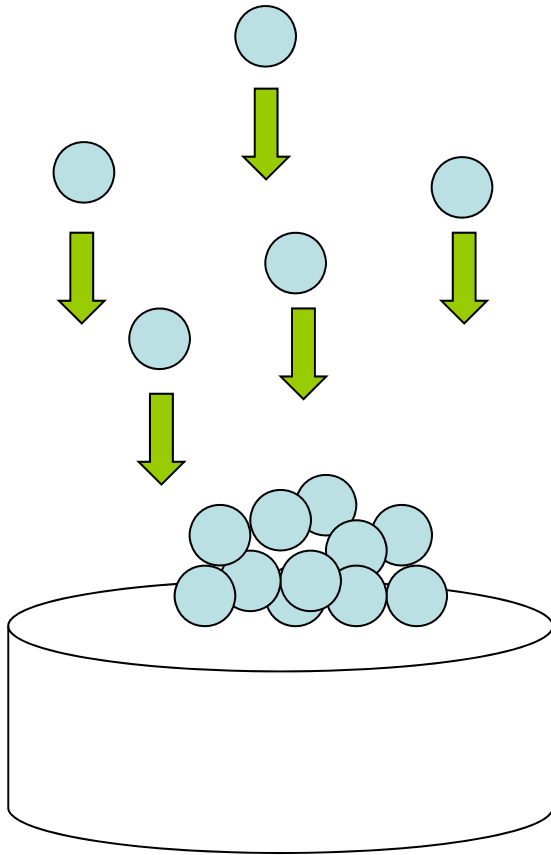
- ダストアグリゲイト模擬物質の作成
 - Random ballistic deposition (RBD) aggregates
- X線CTを用いたダストアグリゲイトの3次元構造の解析
 - fractal dimension,
 - coordination number
 - angler between particles

Sample preparation - Experimental set up -

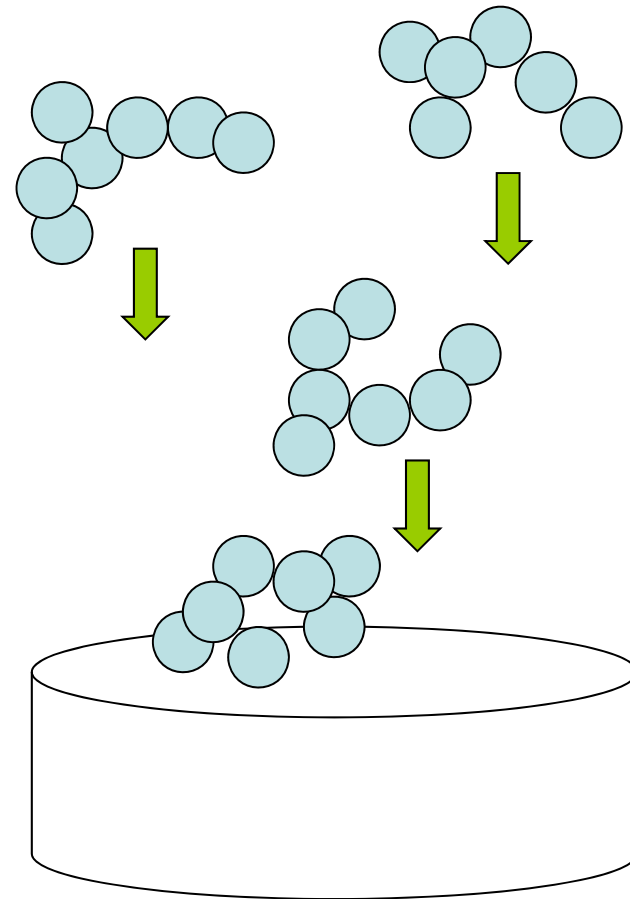


Sample preparation -Experimental condition-

- RBD (Random Ballistic Deposition) monomer

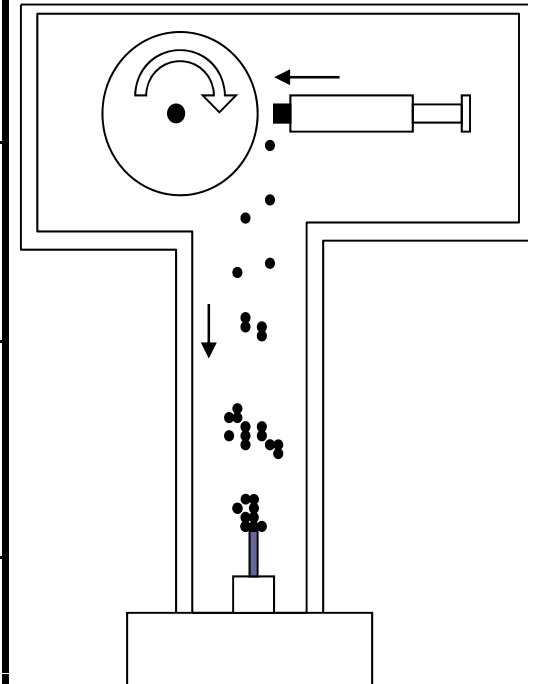


- RBD (Random Ballistic Deposition) cluster



Sample preparation -Experimental condition-

	RBD monomer	RBD cluster
Amounts of dust	small	large
Pressure	low (100Pa)	High (500Pa)
Distance	short	long



Sample preparation -Results-

- RBD (Random Ballistic Deposition) monomer

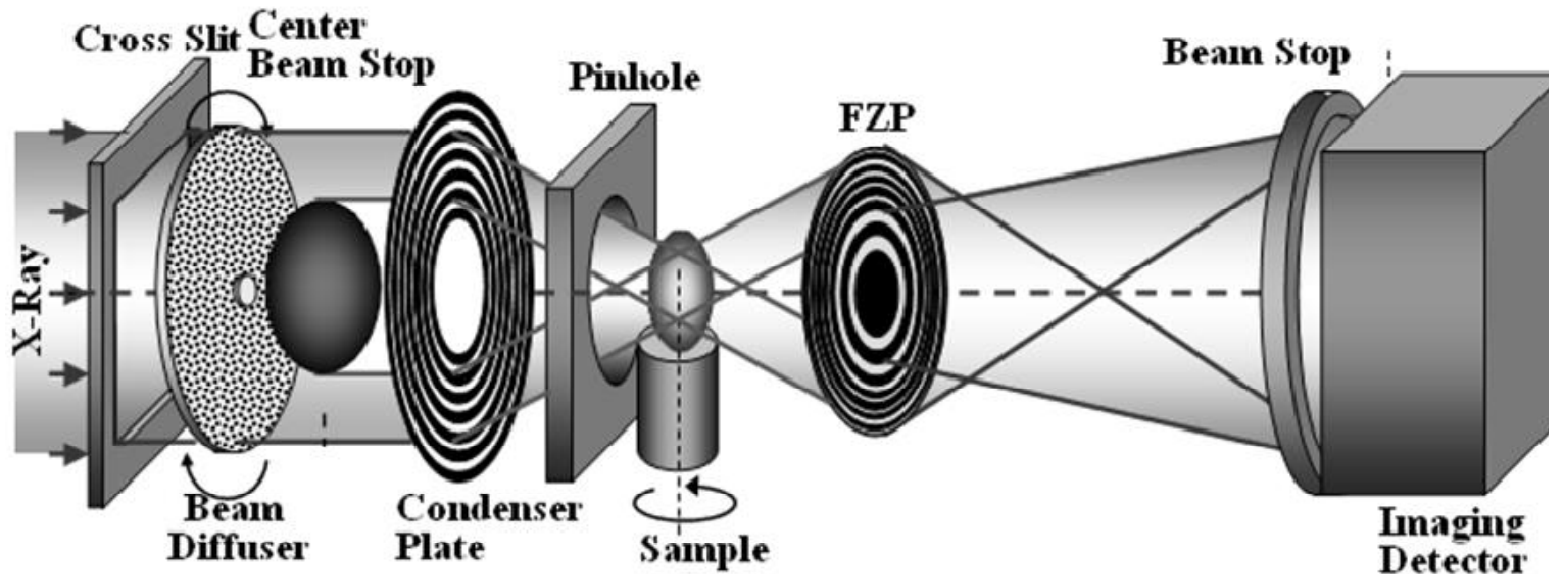


- RBD (Random Ballistic Deposition) cluster



Falling velocity : 0.1 – 1 m/s

X線トモグラフィーを用いた構造解析

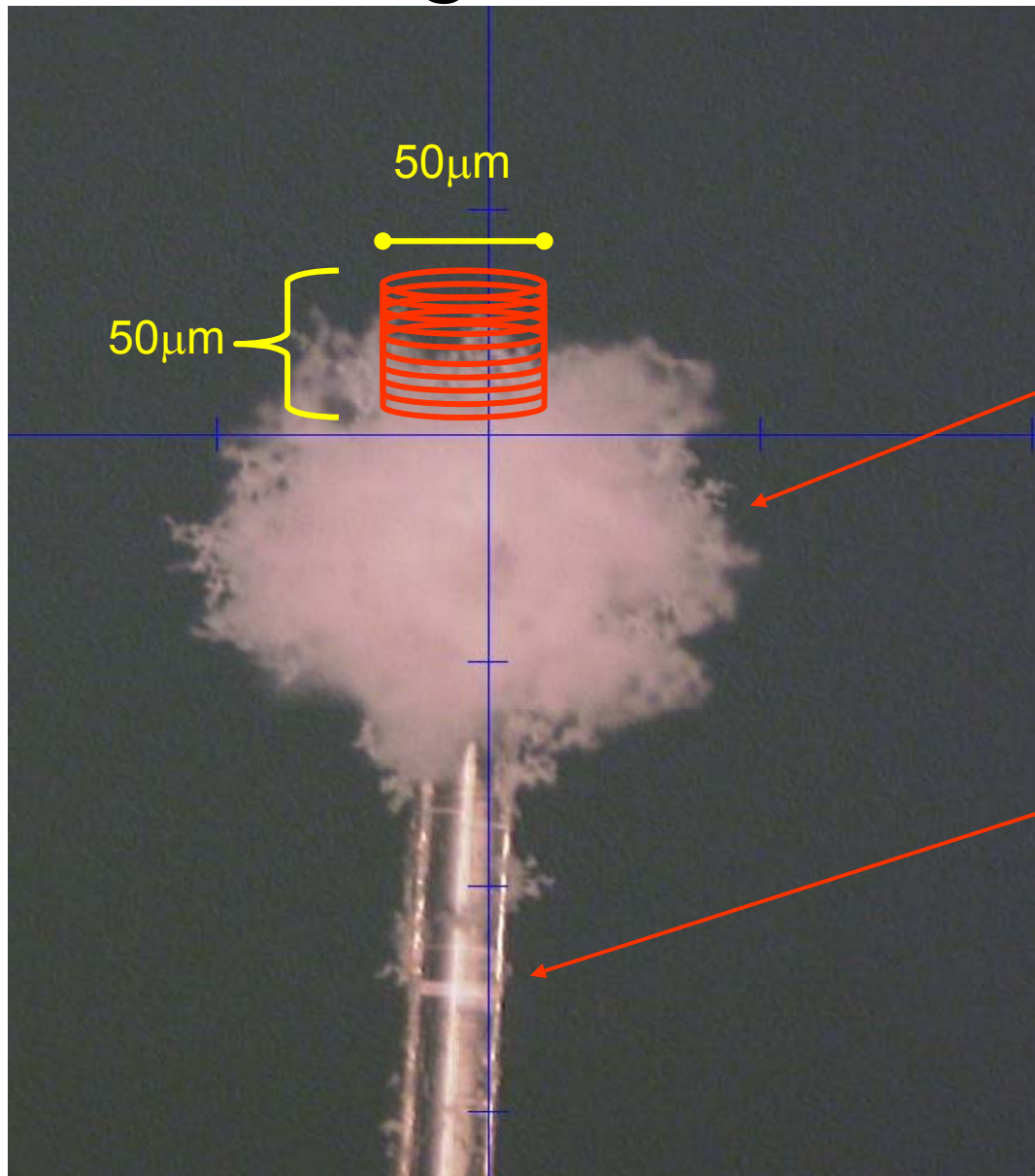


- energy: 8.0 keV
- exposure: 600 msec/projection
- projection number: 800
- resolution: 48 nm/voxel



BL47XU @SPring-8

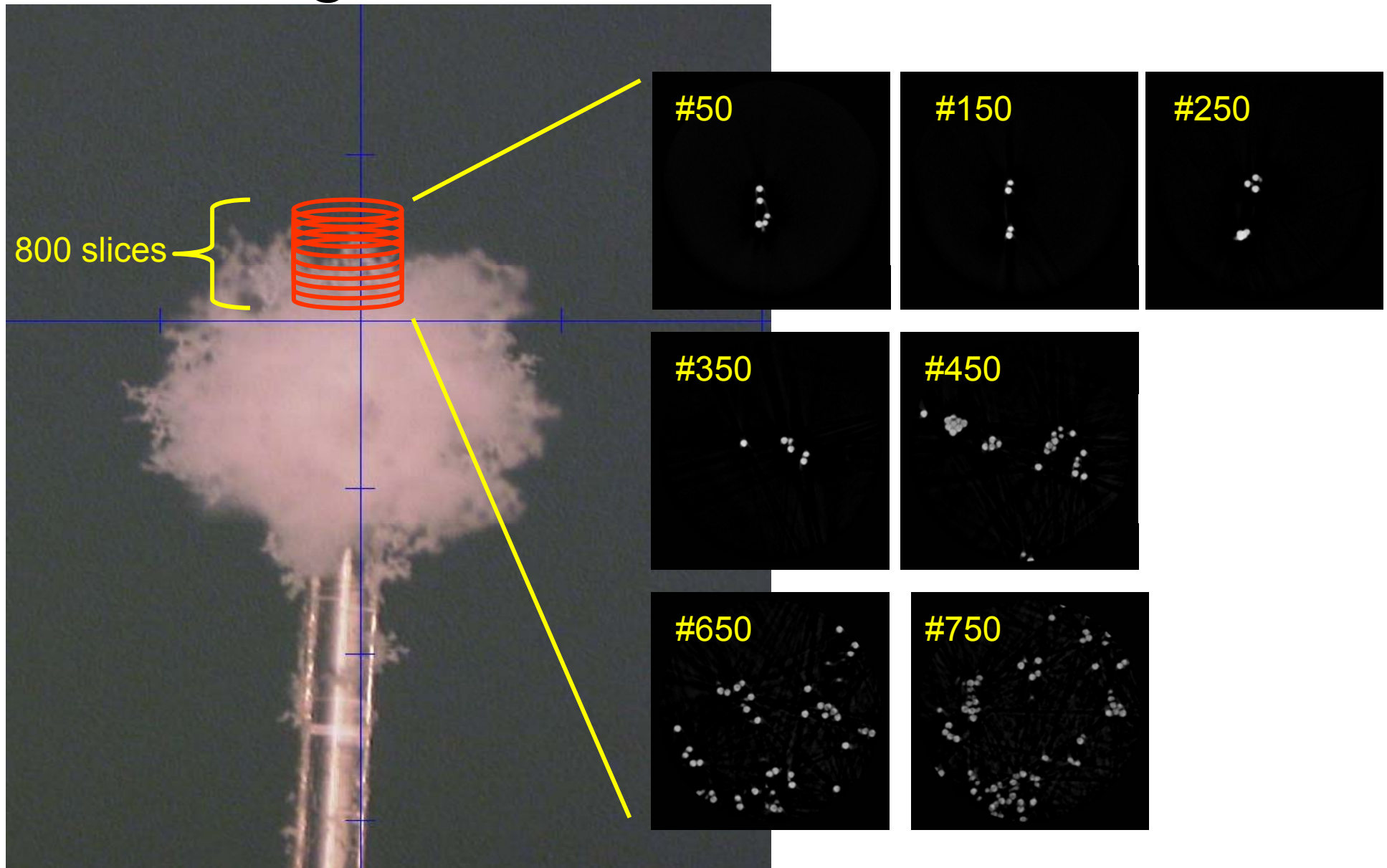
CT Images



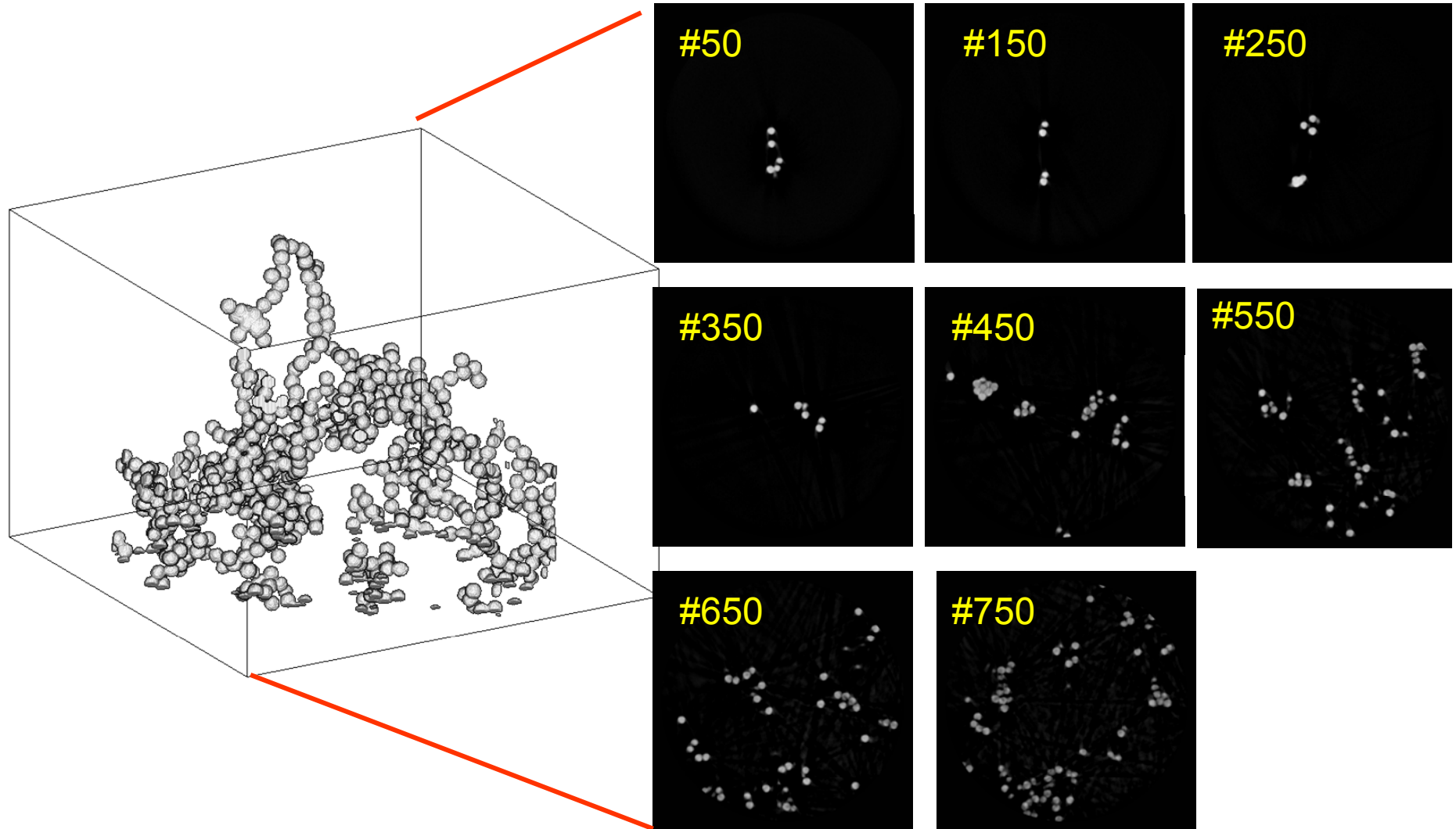
Aggregates

Glass fiber

CT Images

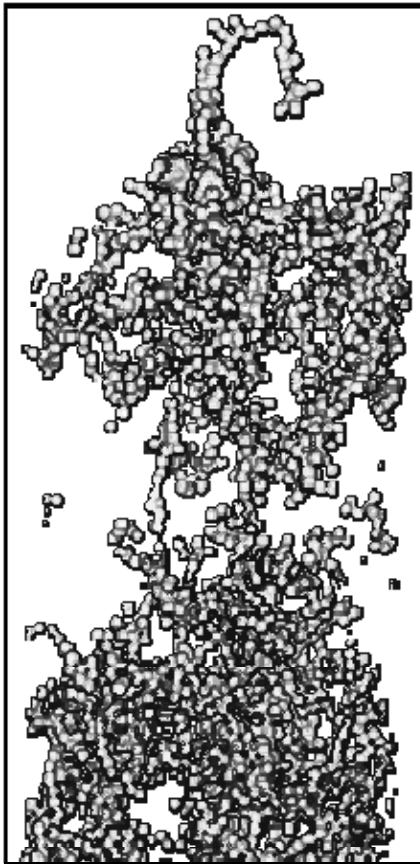


CT Images

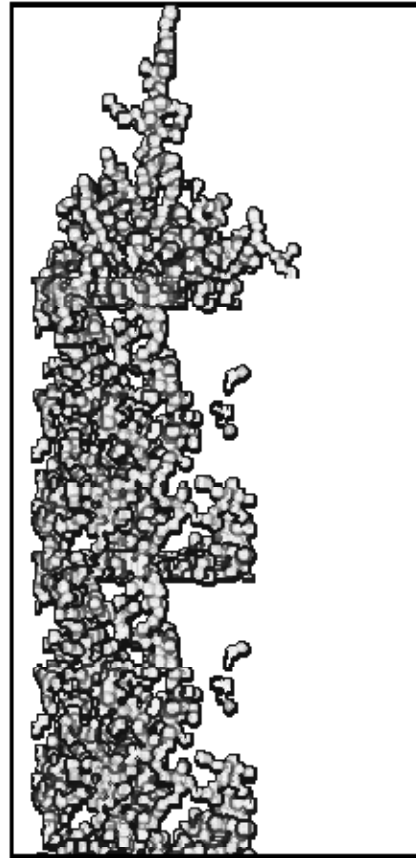


3D CT-Images of The aggregates - RDB monomer -

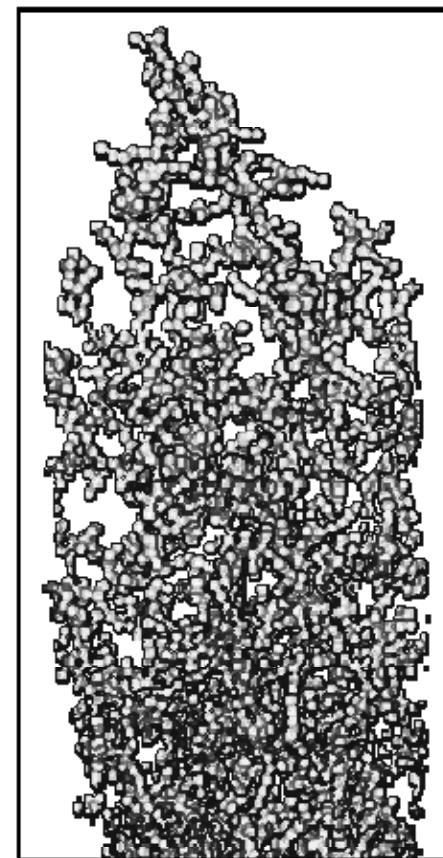
RBD monomer 1



RBD monomer 2

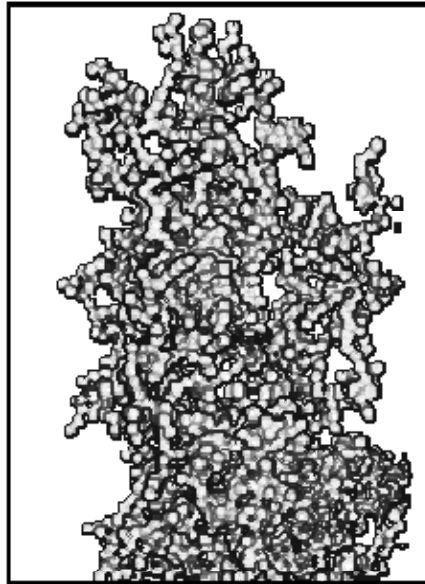


RBD monomer 3

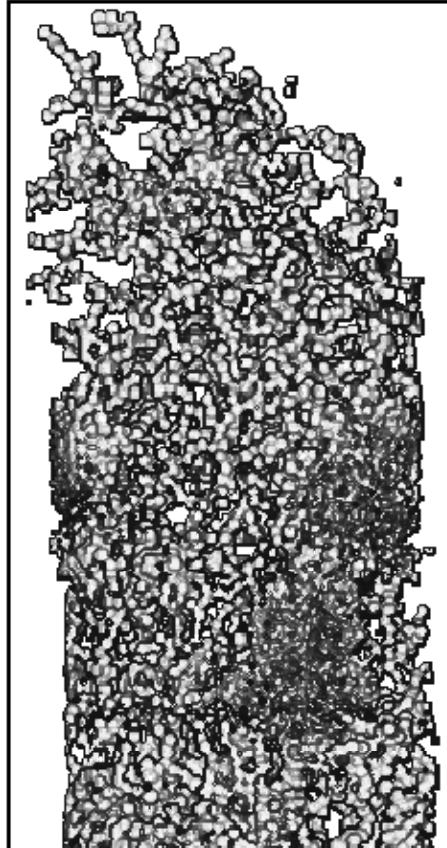


3D CT-Images of The aggregates - RBD cluster -

RBD cluster 1



RBD cluster 2



RBD cluster 3

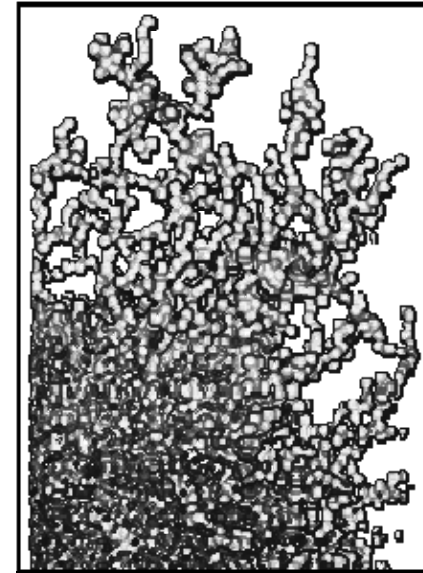
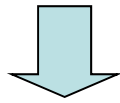
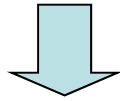


Image Analysis

Original CT image



Binary Image

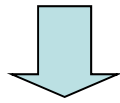


Eroded Image

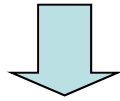


Image Analysis

Original CT image



Binary Image



Eroded Image

Binarization

-> 個々の粒子を認識する。

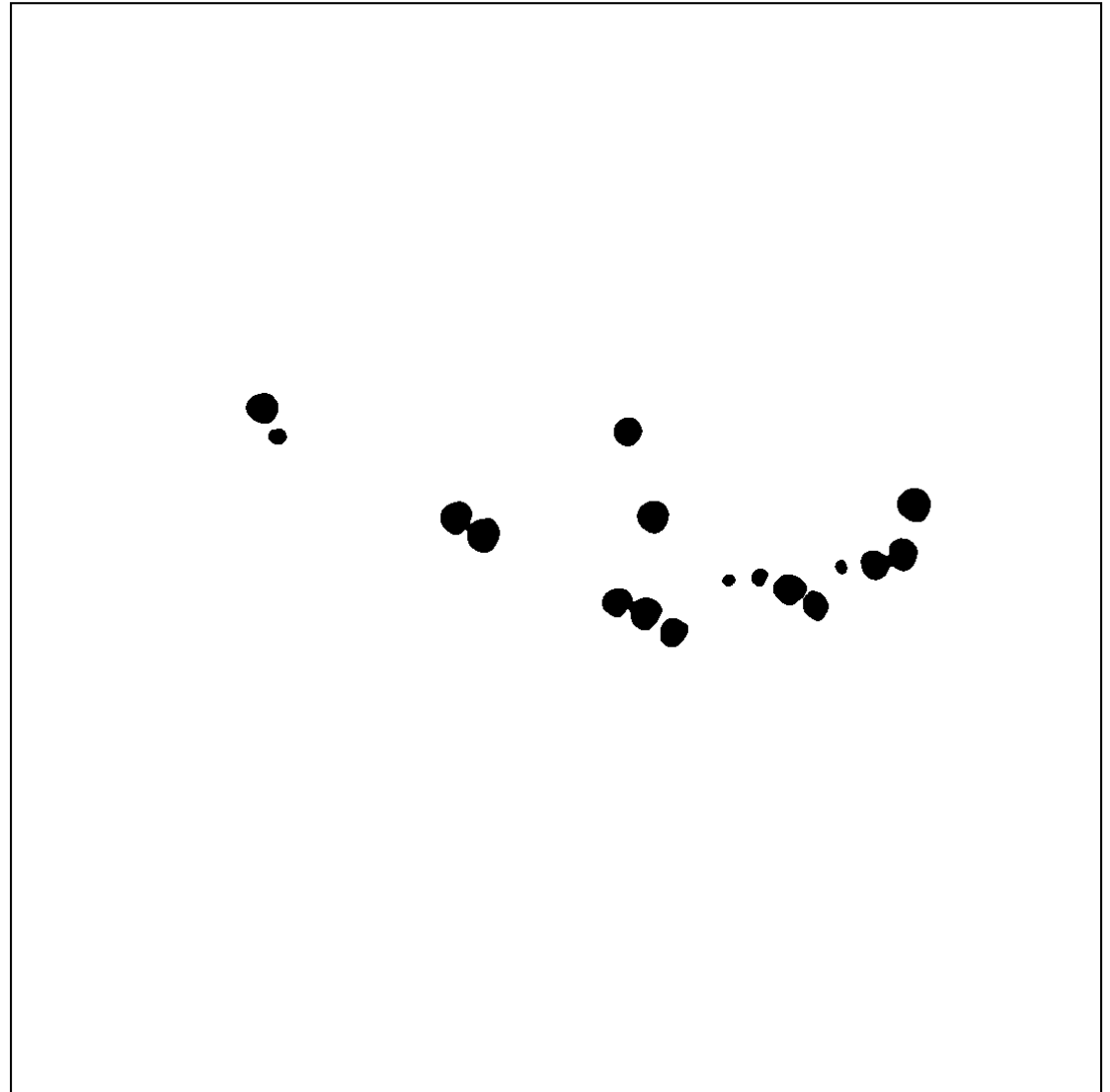
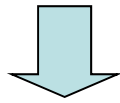
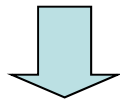


Image Analysis

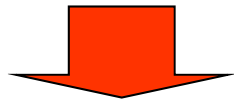
Original CT image



Binary Image



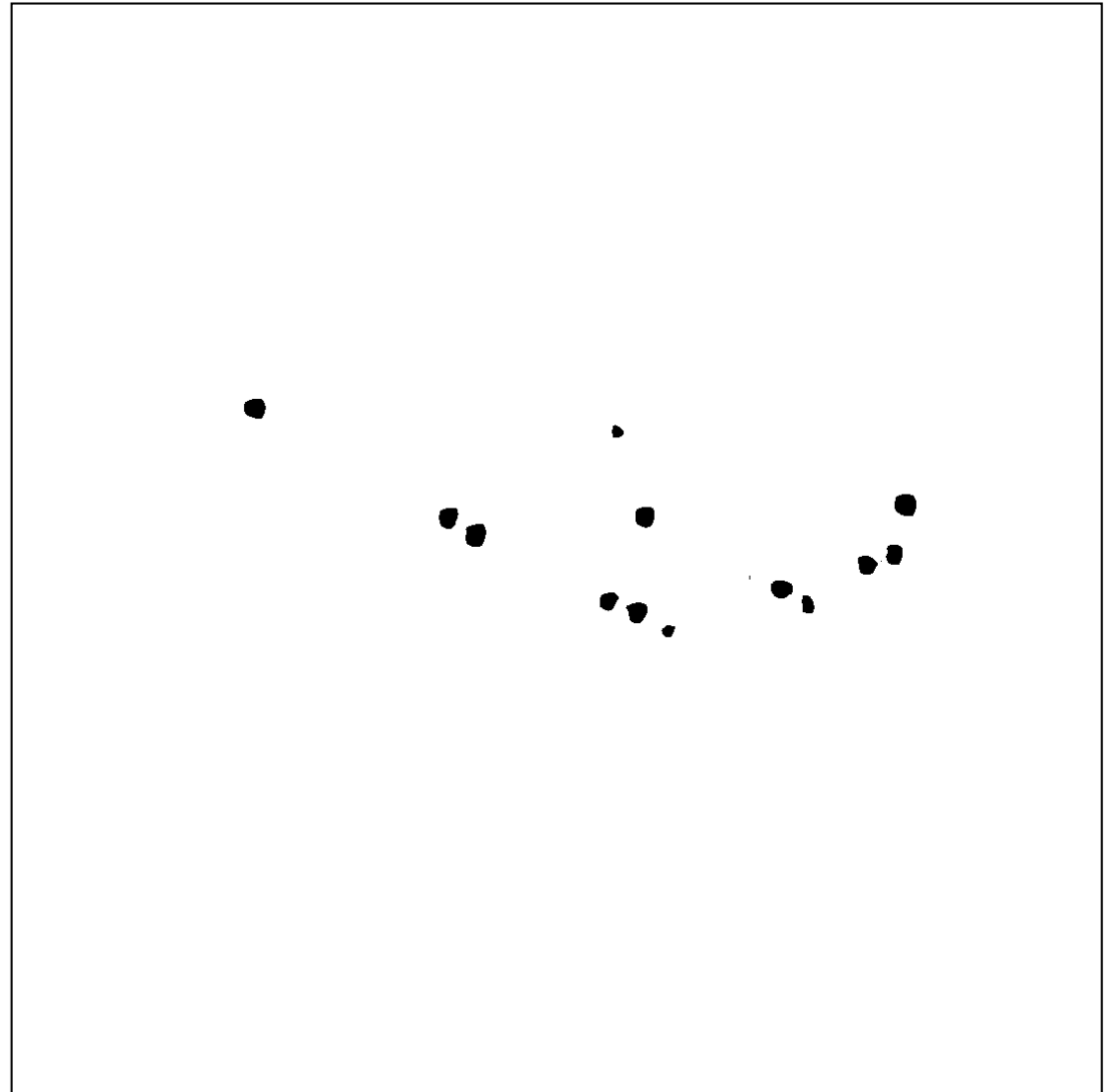
Eroded Image



個々の粒子の重心位置を
求めることができた。

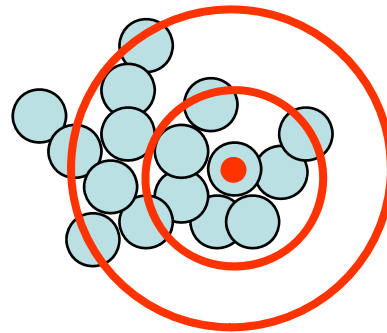
Erosion

-> 粒子を分離する。



Fractal dimension

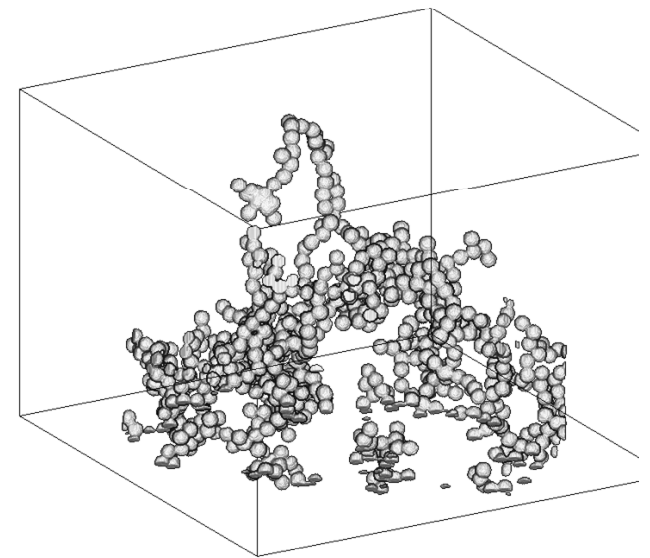
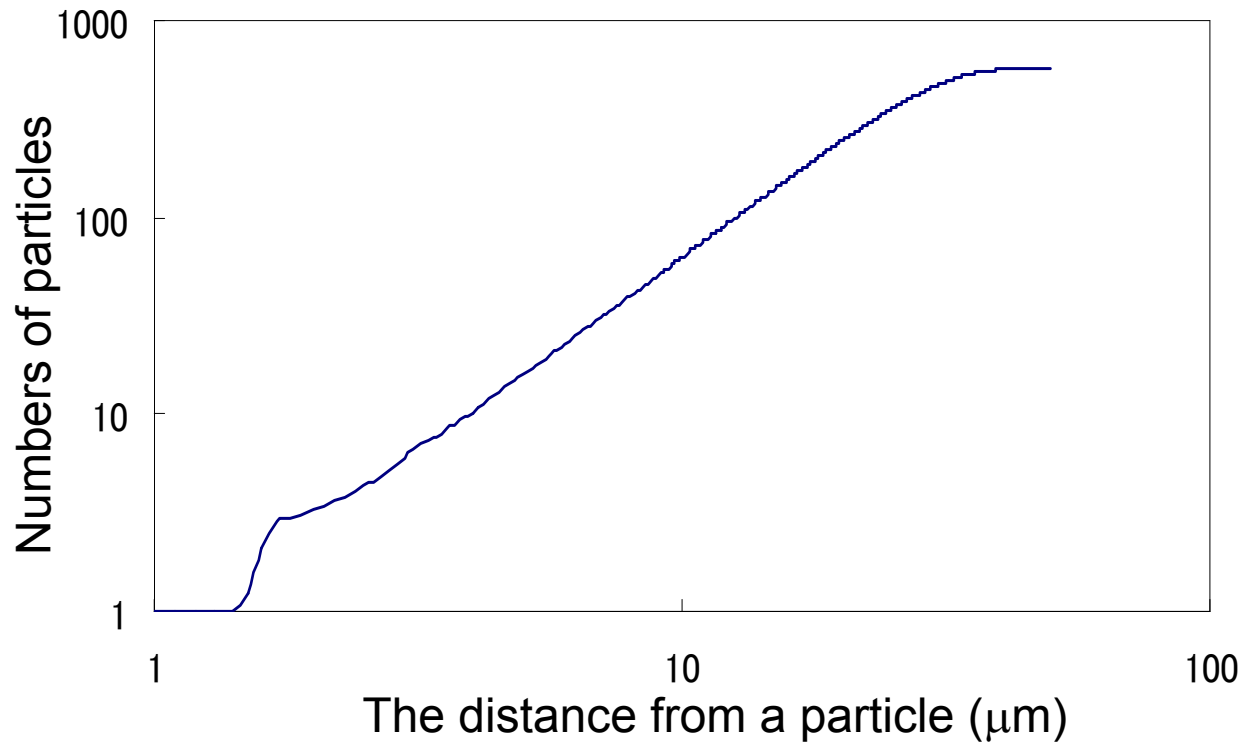
$$d \equiv \frac{d \ln N(r)}{d \ln r}$$



Compact dust: $d=3.0$

BCCA: $d = 2.0-2.5$

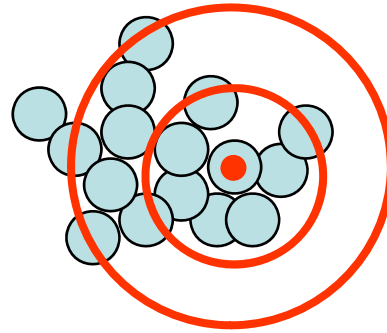
r : The distance from a particle
 N : Number of particles inner r



RBD monomer 1
(surface)

Fractal dimension

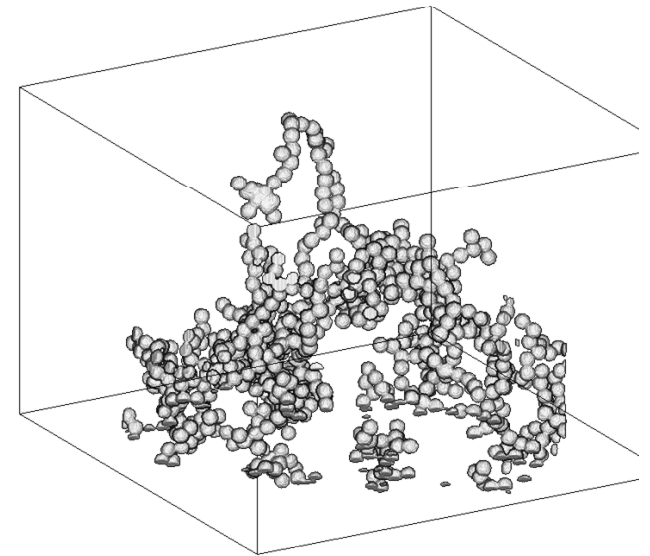
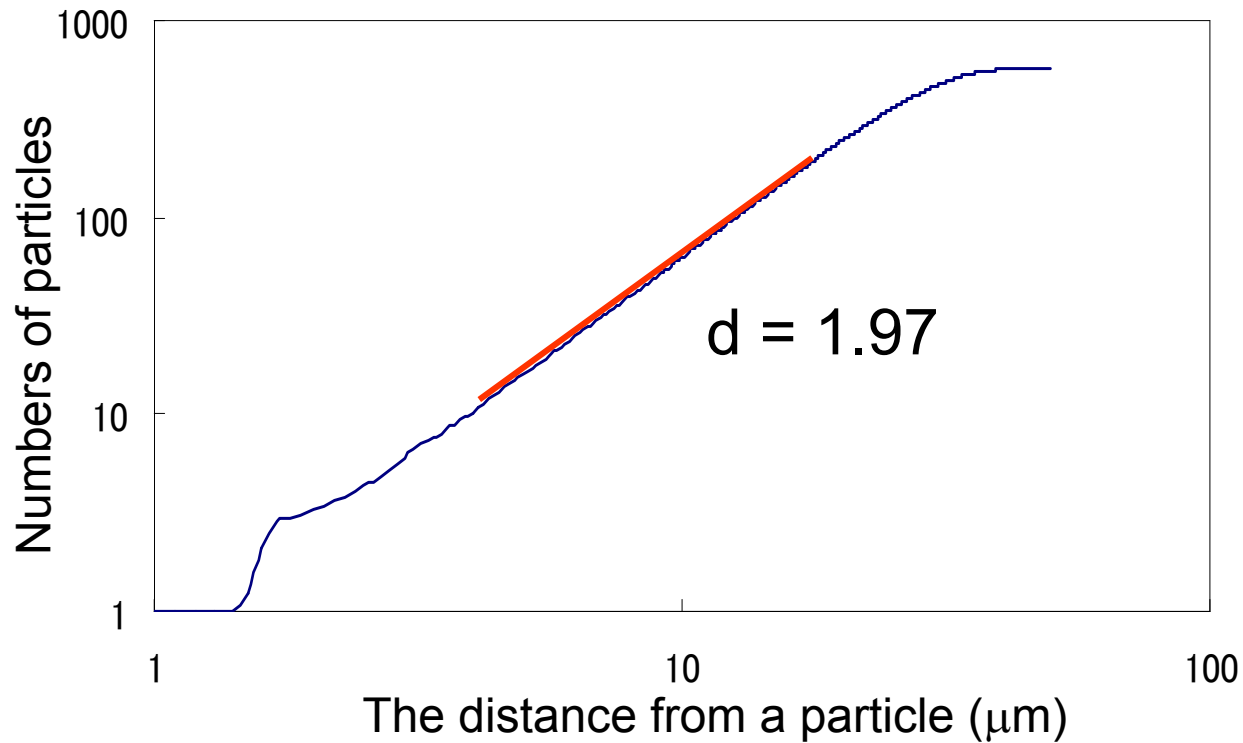
$$d \equiv \frac{d \ln N(r)}{d \ln r}$$



Compact dust: $d=3.0$

BCCA: $d = 2.0-2.5$

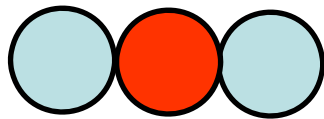
r : The distance from a particle
 N : Number of particles inner r



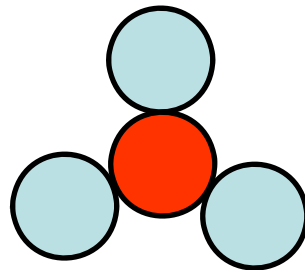
RBD monomer 1
(surface)

Coordination Number (配位数)

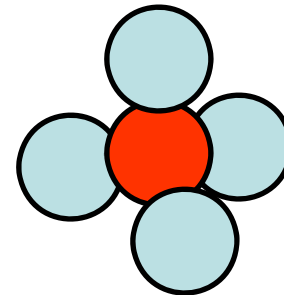
- Coordination number : C.N.
 - Number of particles in contact with a particle.



C.N. = 2



C.N. = 3

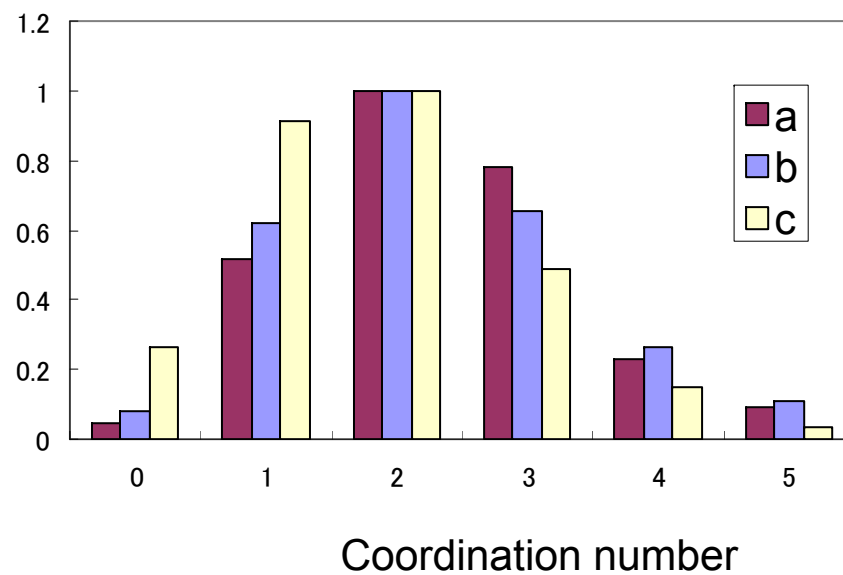
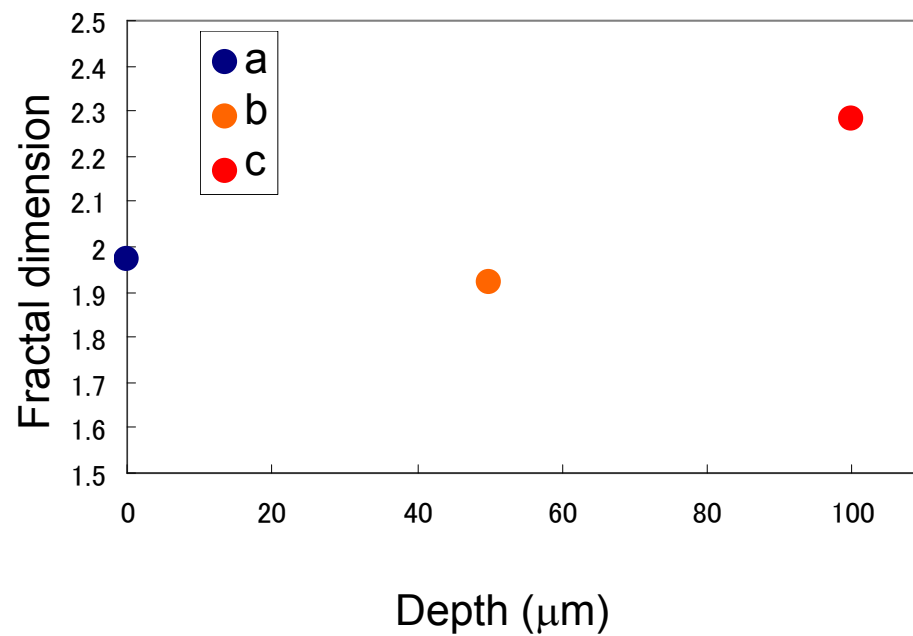
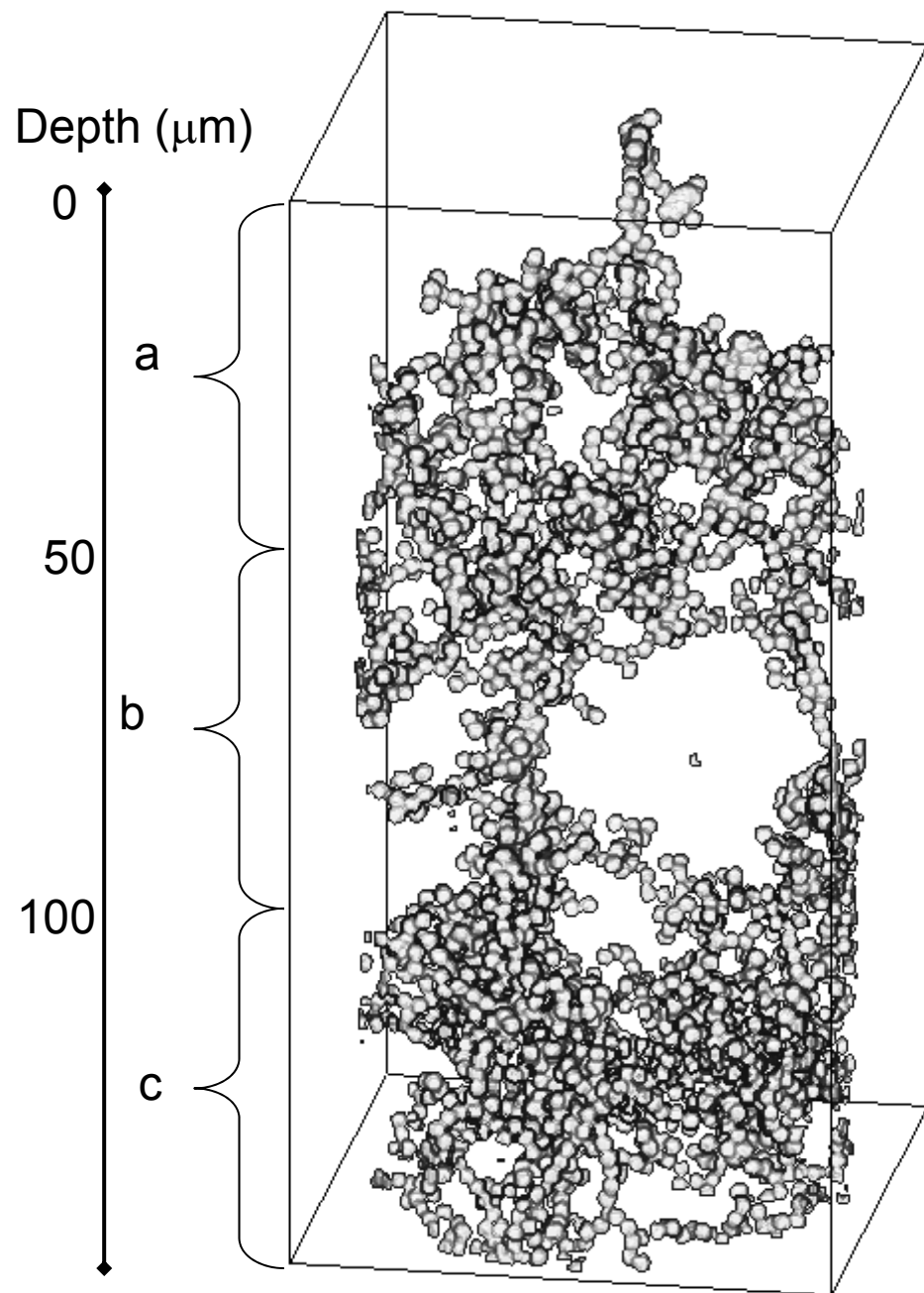


C.N. = 4

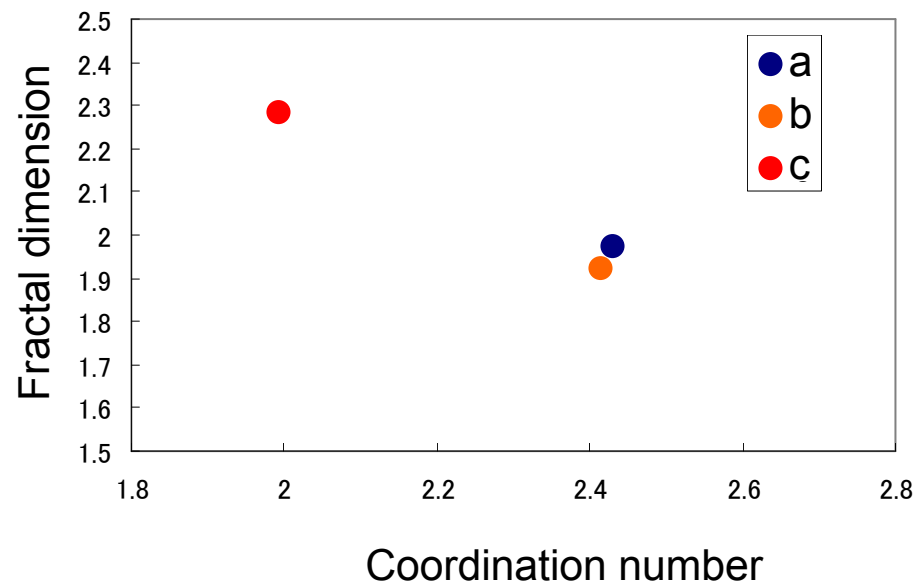
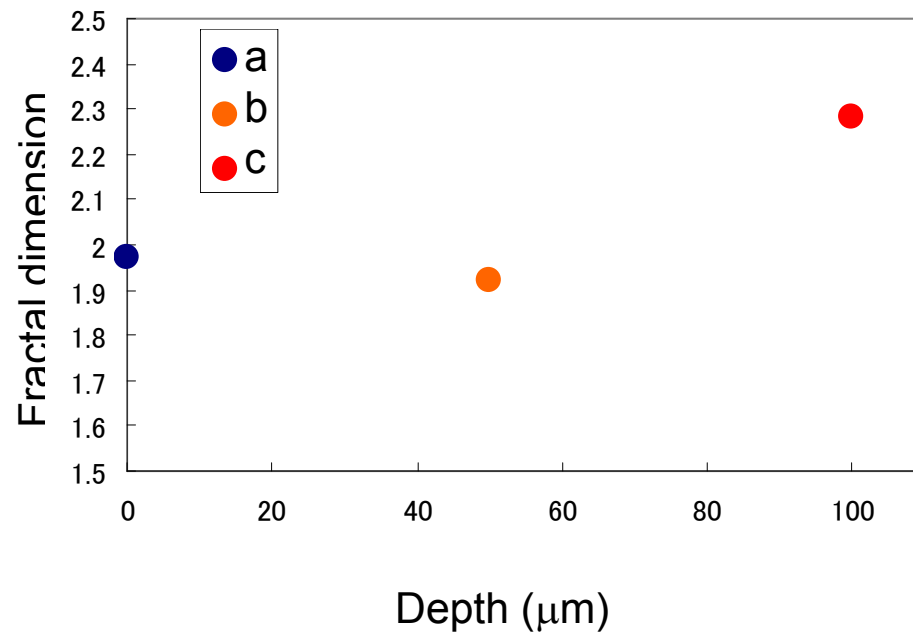
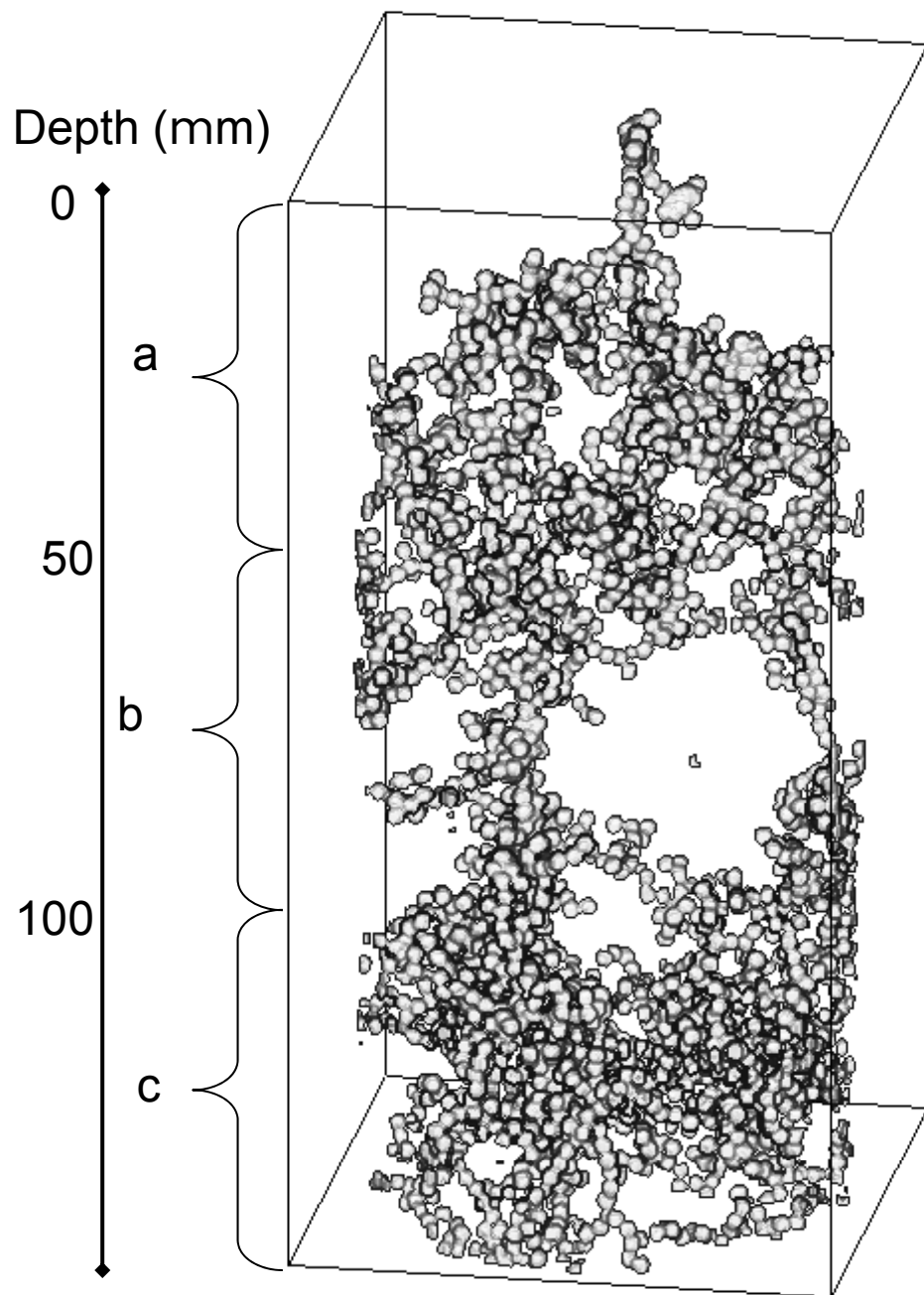


Aggregates of numerical simulations: C.N.= 2-4

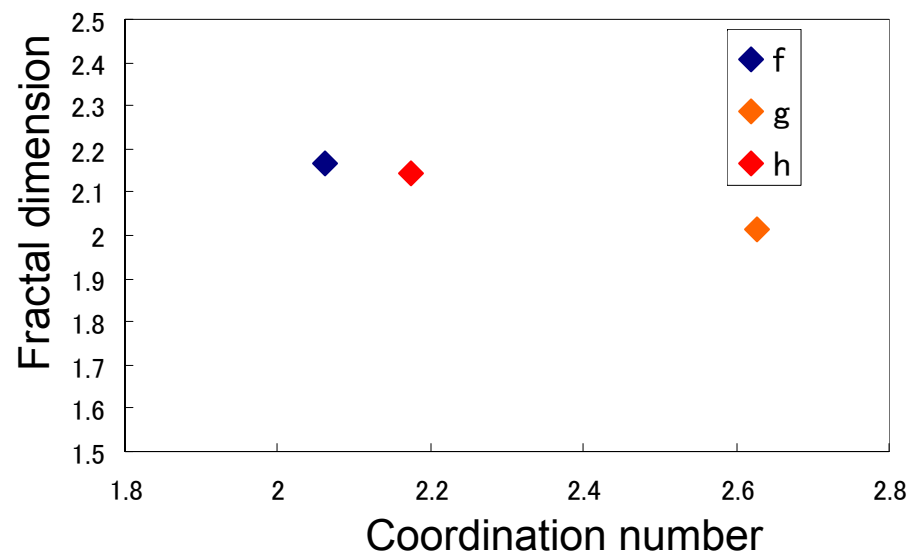
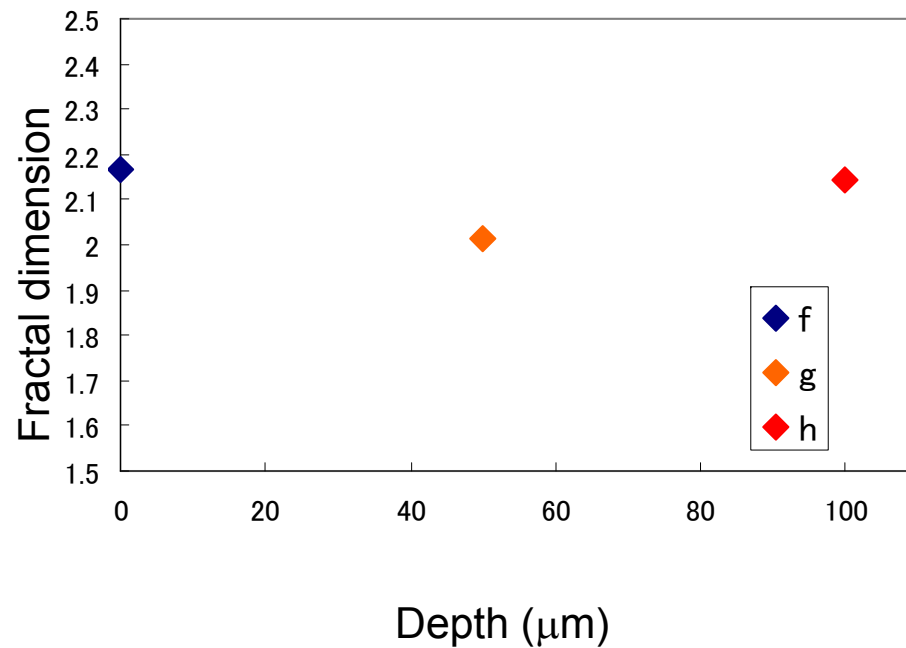
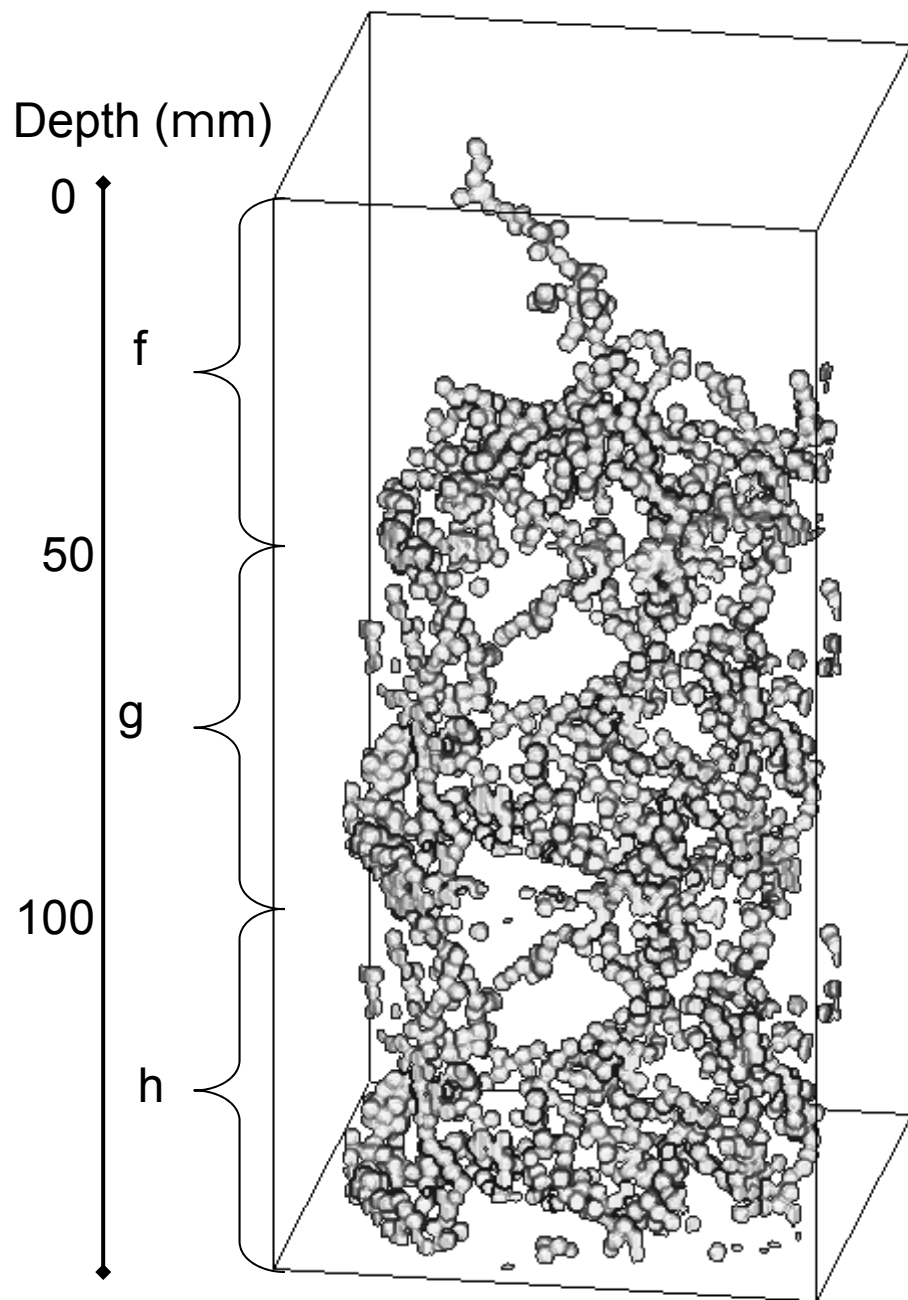
RBD monomer 1



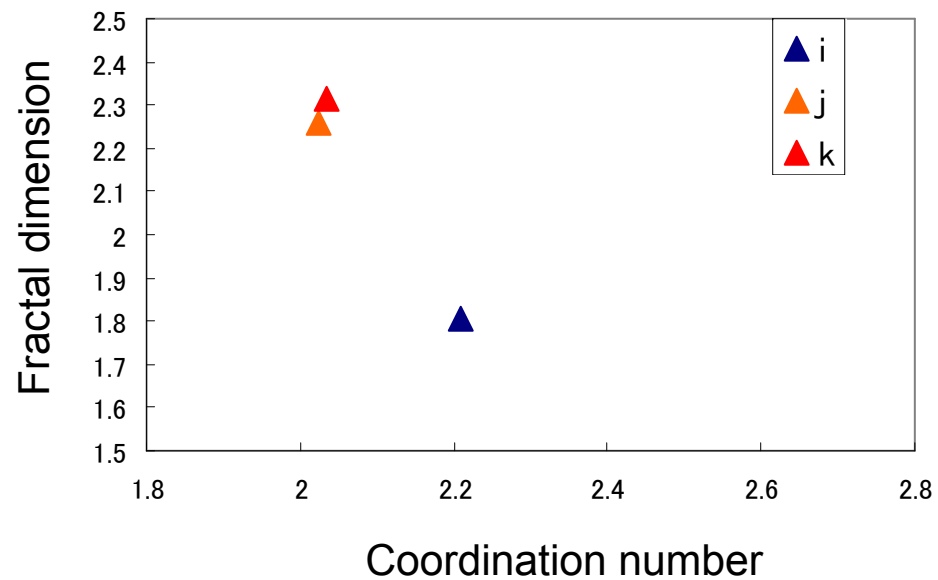
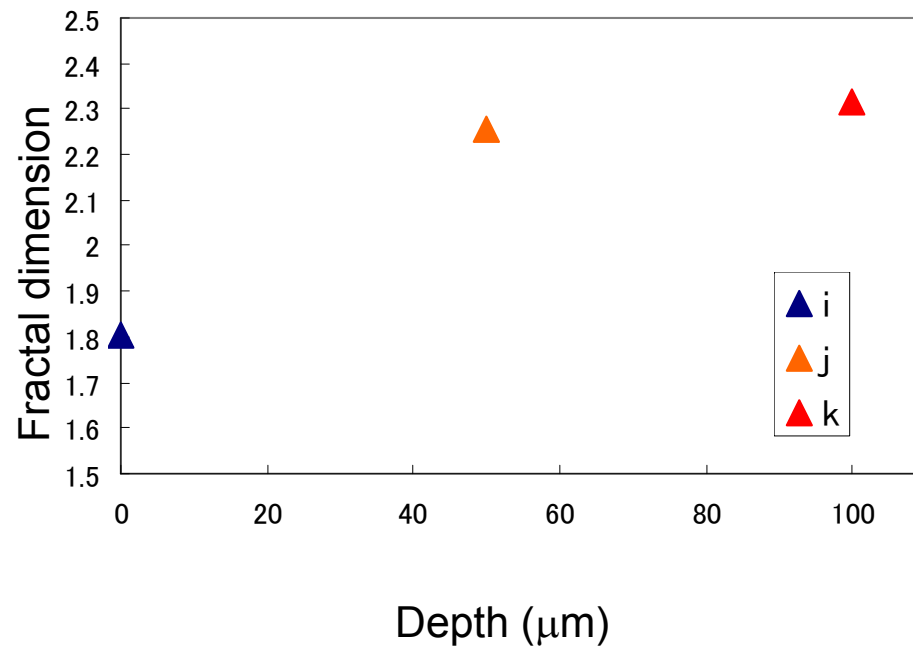
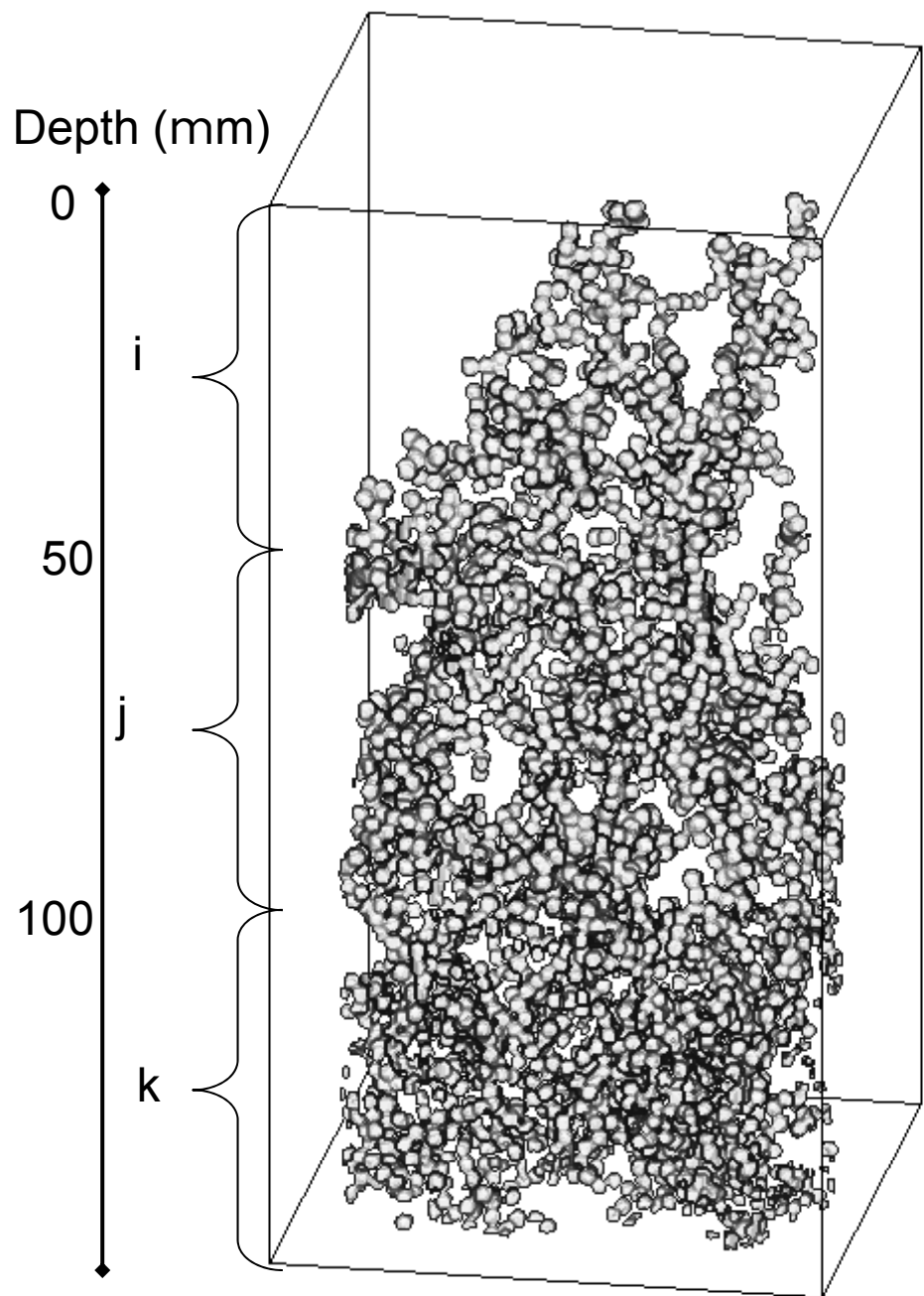
RBD monomer 1



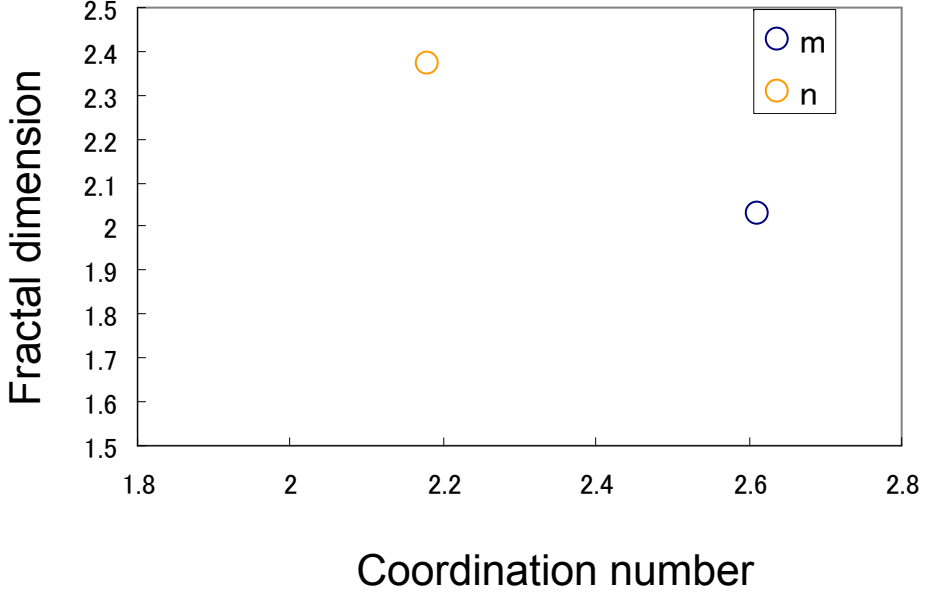
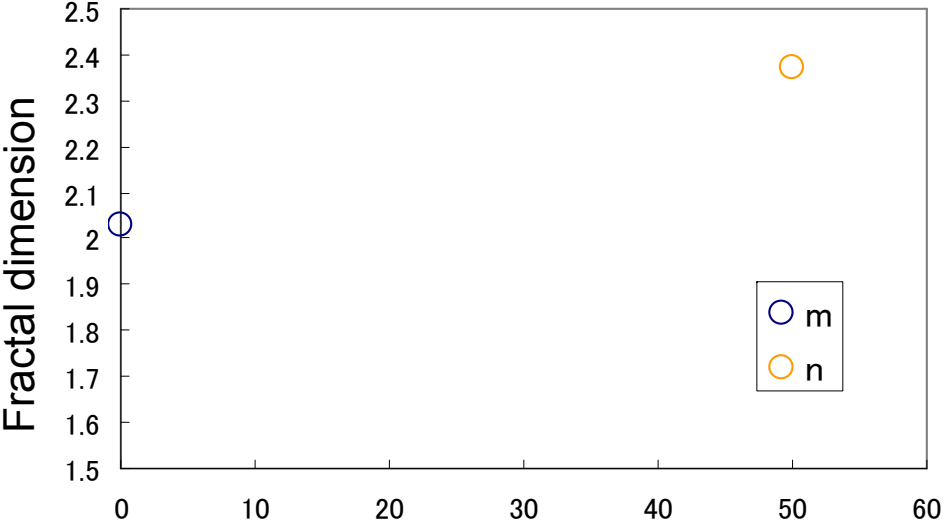
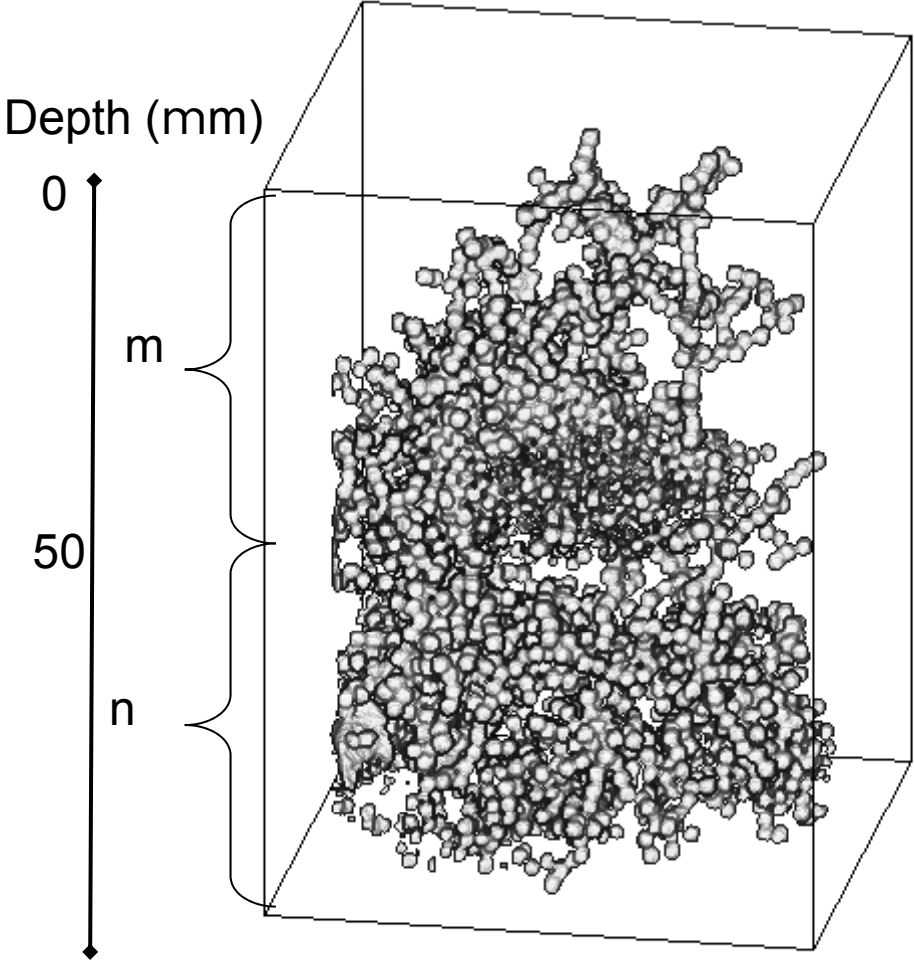
RBD monomer 2



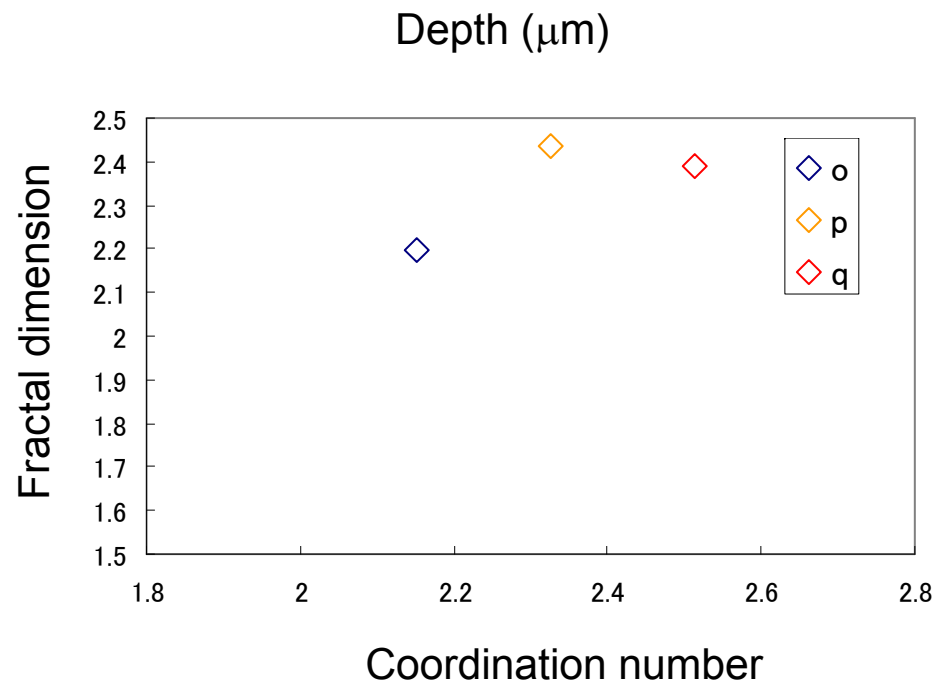
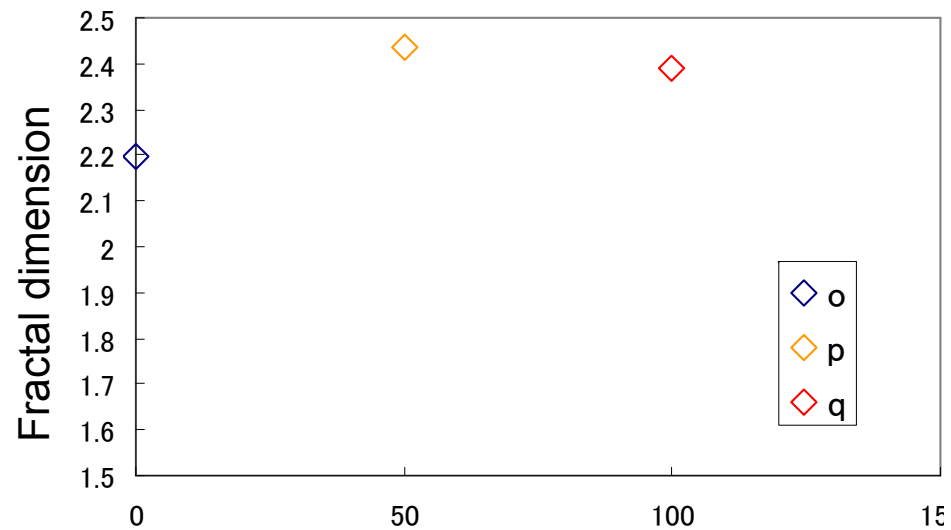
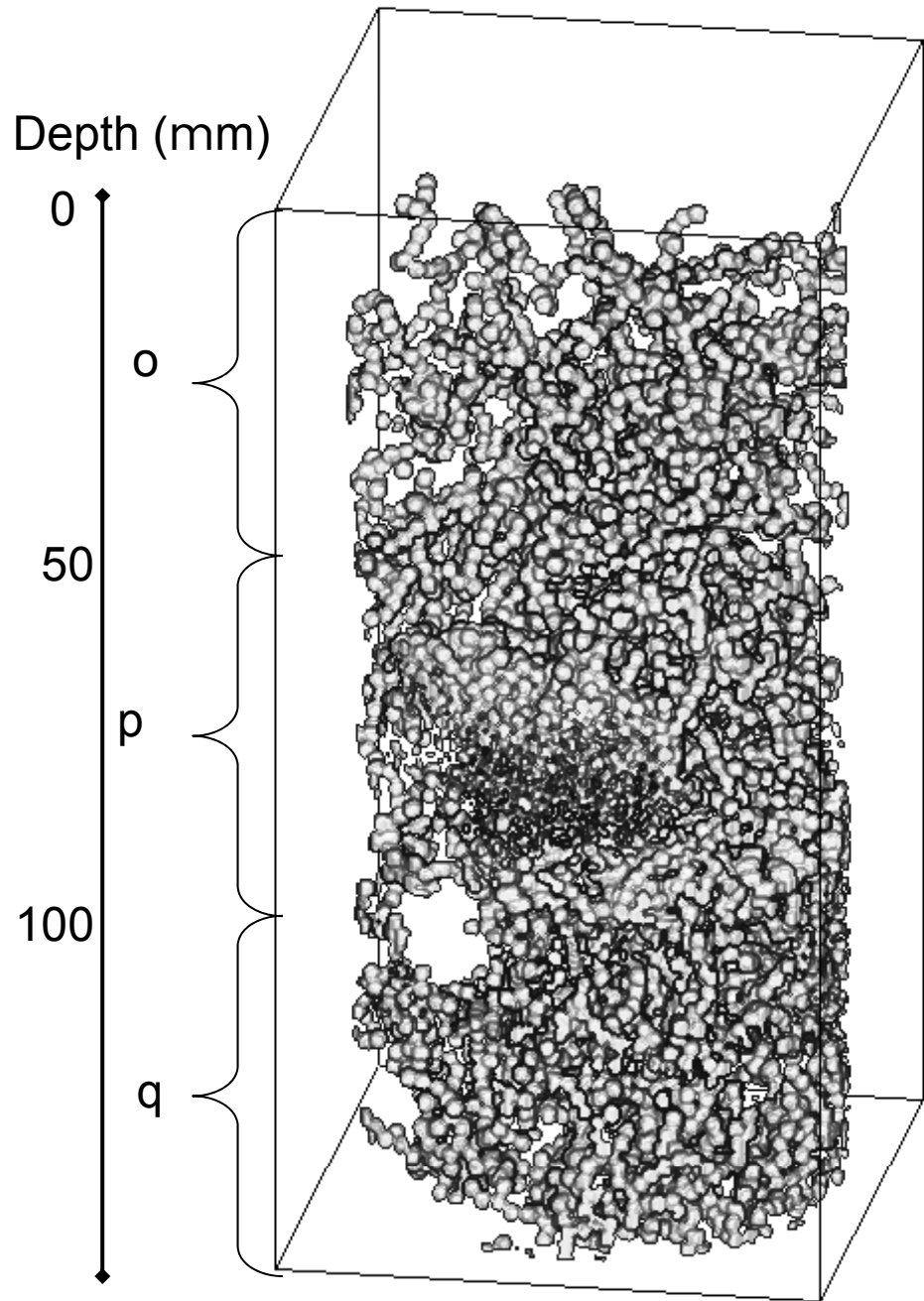
RBD monomer 3



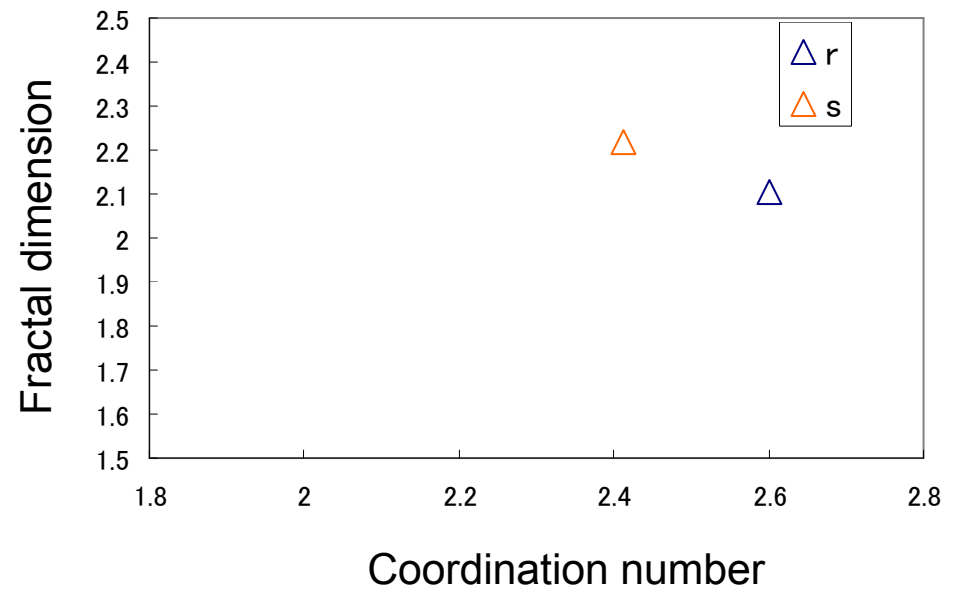
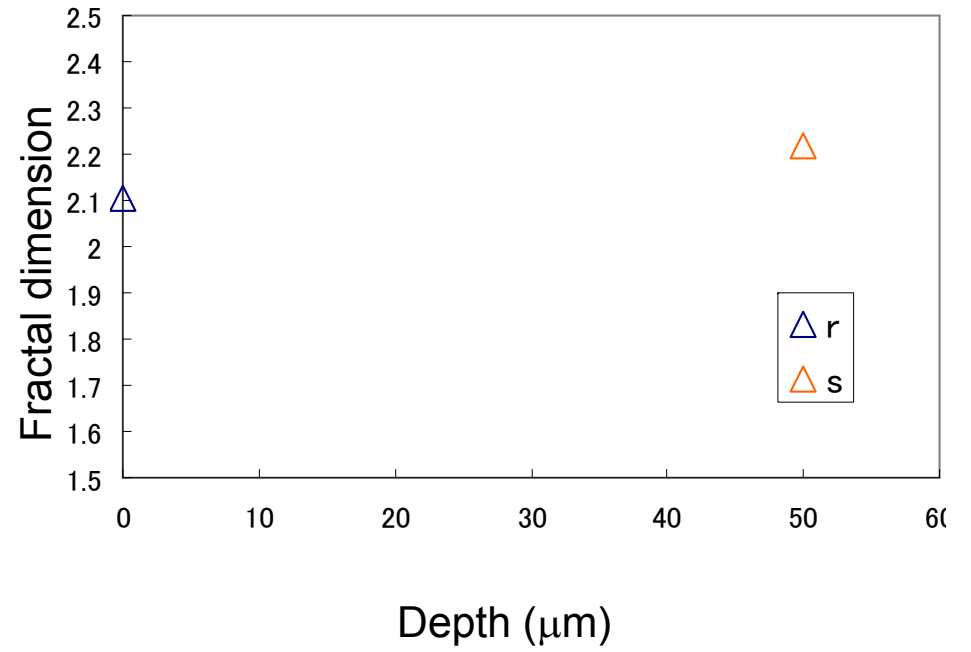
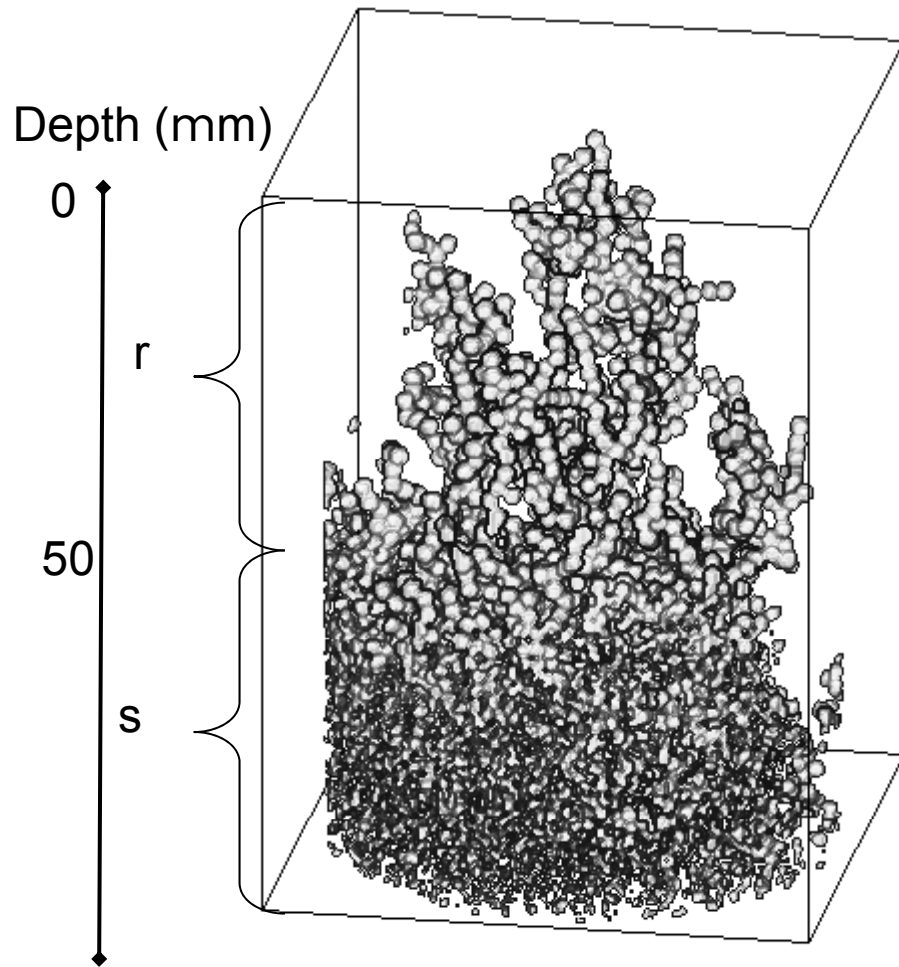
RBD cluster 1



RBD cluster 2

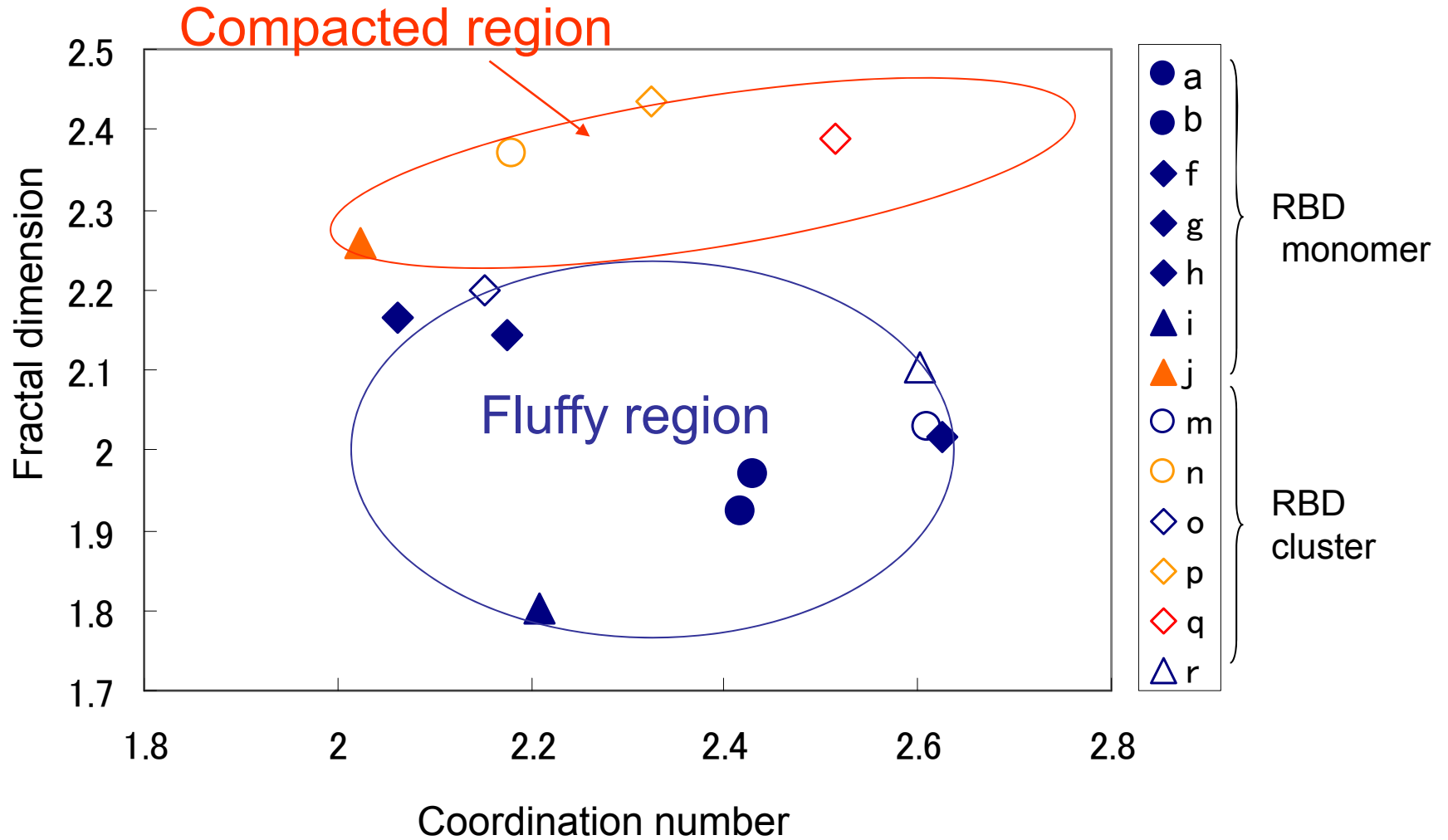


RBD cluster 3

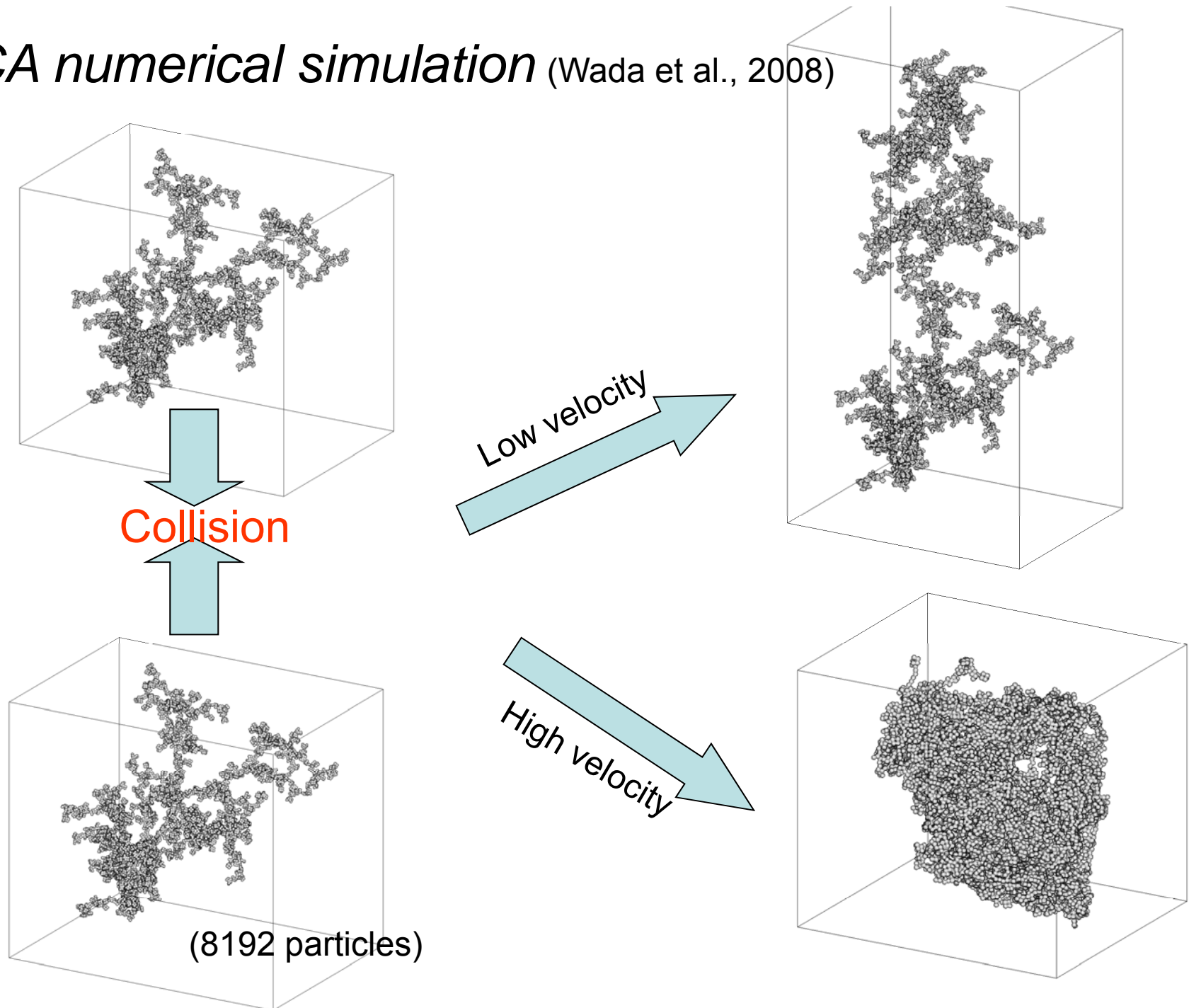


Experimental results

- Relation between coordination number and fractal dimension

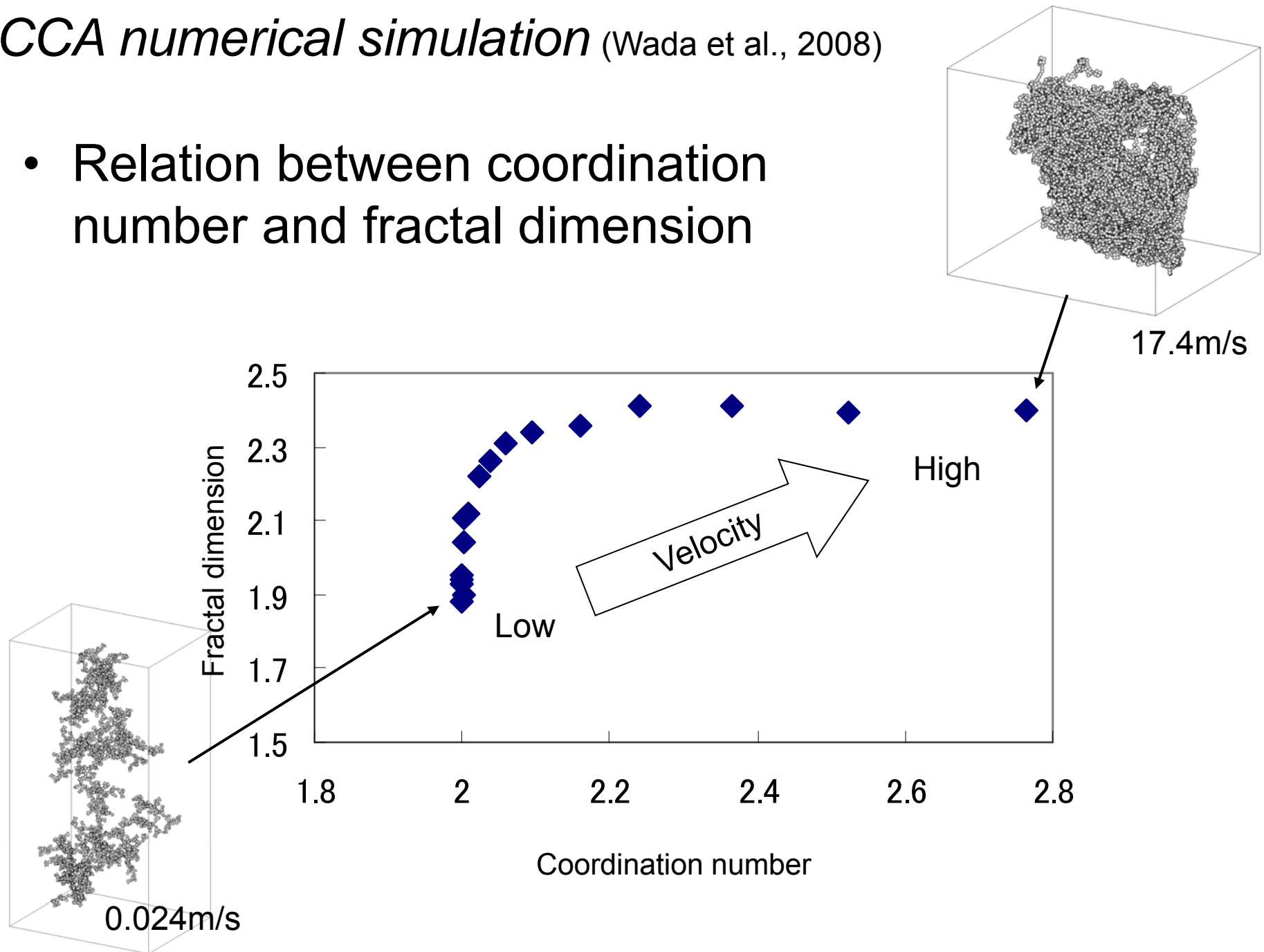


BCCA numerical simulation (Wada et al., 2008)



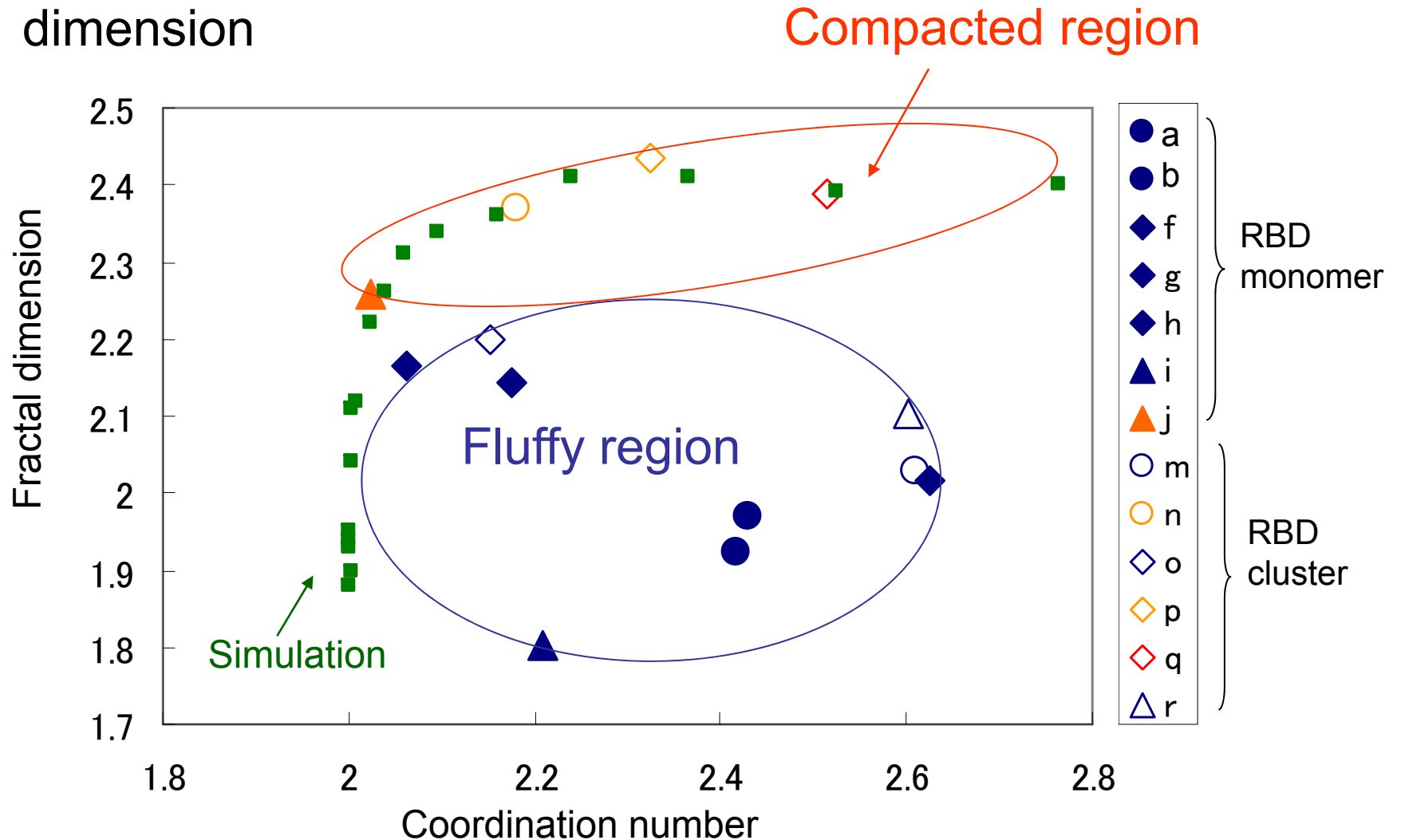
BCCA numerical simulation (Wada et al., 2008)

- Relation between coordination number and fractal dimension

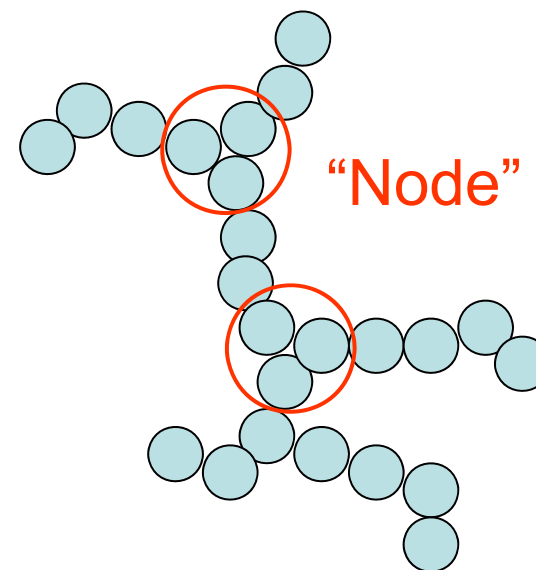
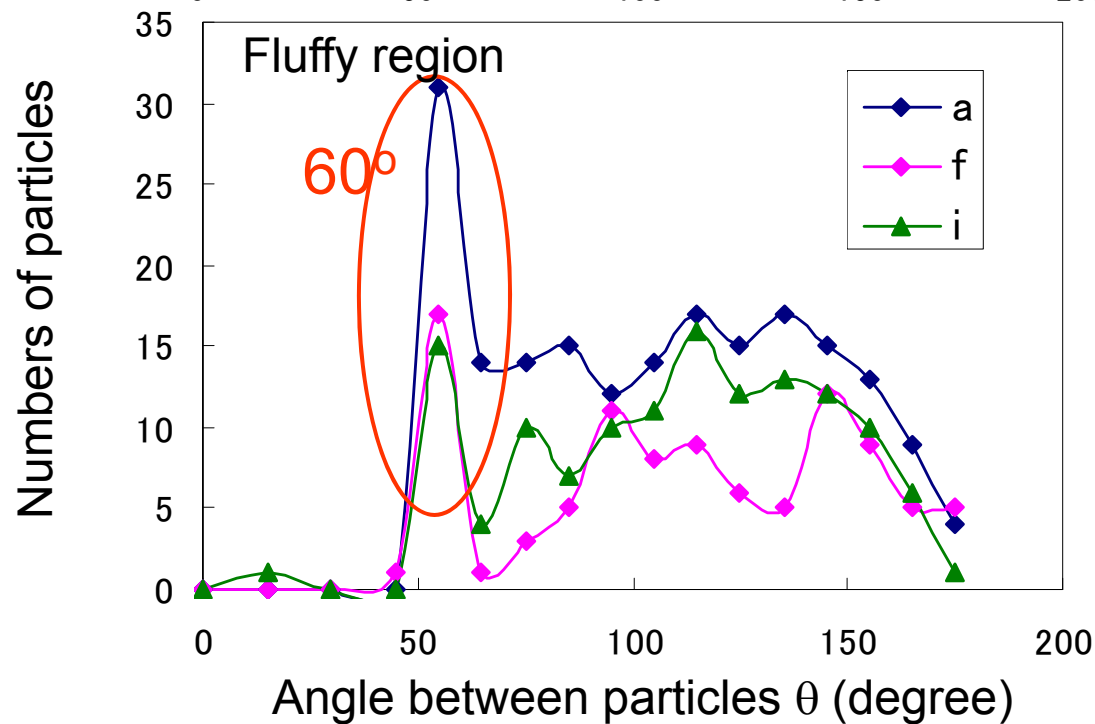
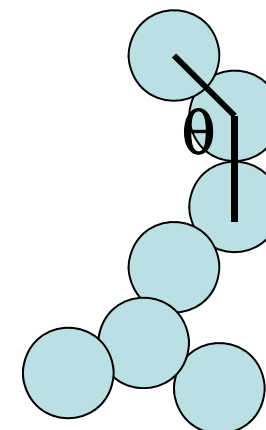
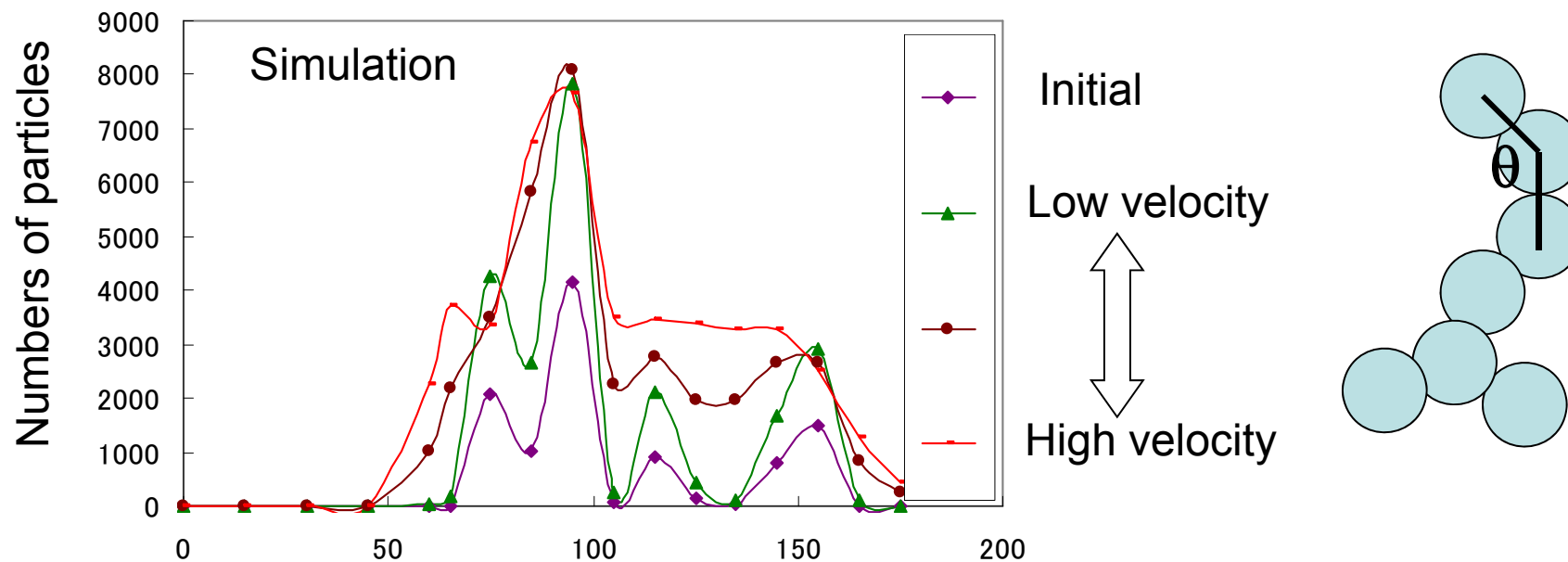


Comparison between the experiments and simulation.

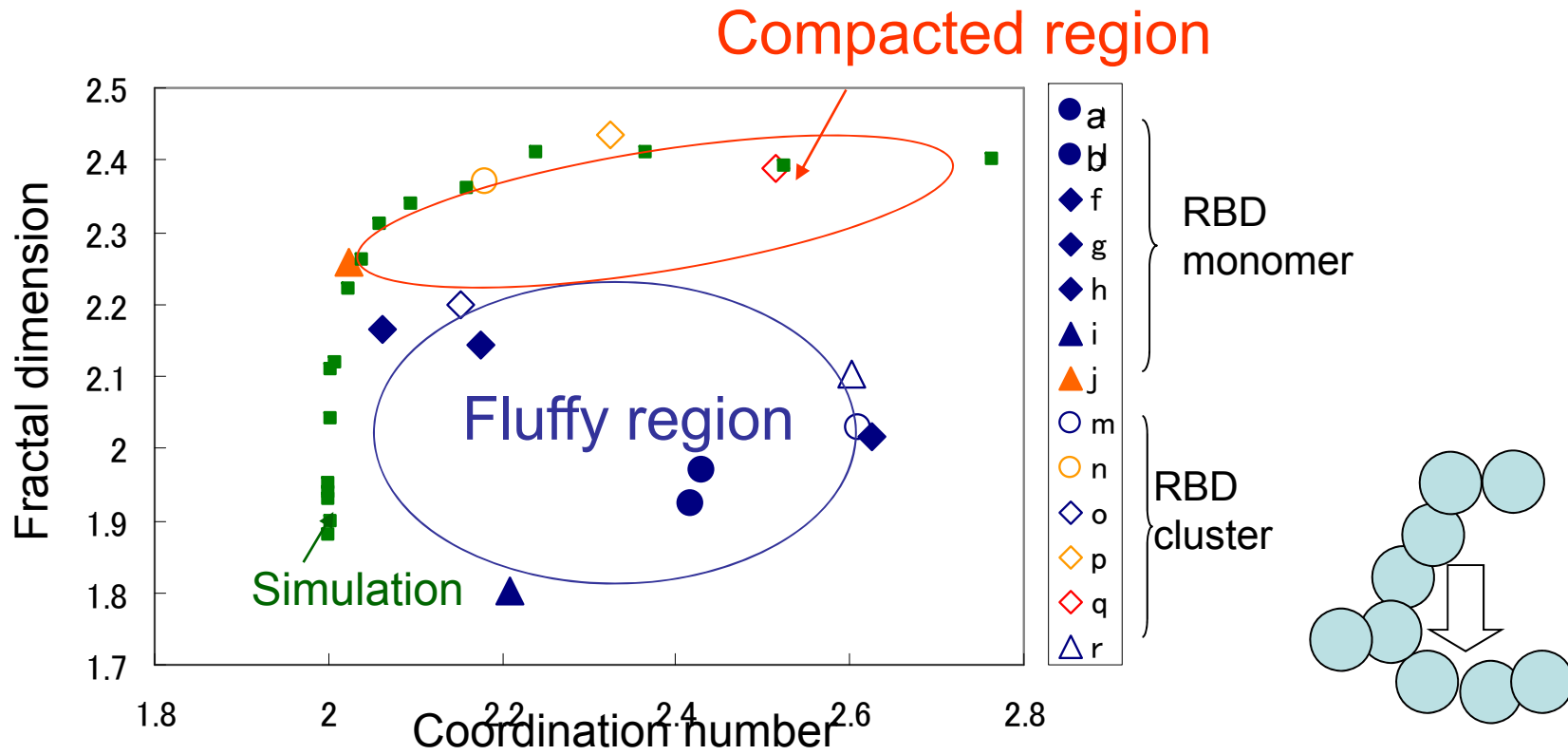
- Relation between coordination number and fractal dimension



Difference of structures between simulation and experiment



Comparison between the experiments and simulation.

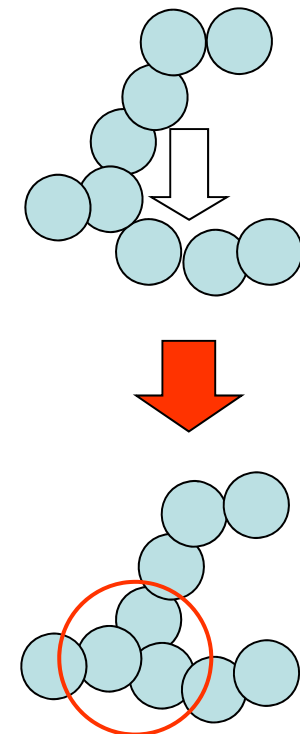


- 実験で作ったFluffy なダストアグリゲイトは、シミュレーションと比べ配位数が大きい。



フラクタル次元が同じでも....
異なった3次元構造を持っている

(e.g., Node, BCCA vs RBD)



Summary

- ダスタアグリゲイトの模擬物質を実験的に作成し、その3次元構造をX線CTを用いて観察した。
- その結果、アグリゲイトの個々の粒子を認識することができ、アグリゲイトのフラクタル次元・配位数・粒子同士のつながりの角度を求めることが可能となった。
- 得られた結果を、BCCAの数値シミュレーションの結果と比較したところ、コンパクトな部分ではコンシステントな結果が得られたが、Fluffy なものでは配位数に違いが見られ、同じフラクタル次元を持っていても、3次元構造が違うことが明らかになった。

