## CHAPTER 4

## CLAY MINERALS, SOIL AND ROCK STRUCTURES, AND ROCK CLASSIFICATION

4-1. Calculate the specific surface of a cube (a) 10 mm , (b) 1 mm , (c) and (d) 1 nm on a side.
Calculate the specific surface in terms of both areas and $\mathrm{m}^{2} / \mathrm{kg}$. Assume for the latter case that $\rho_{\mathrm{s}}$
$=2.65 \mathrm{Mg} / \mathrm{m}^{3}$.
SOLUTION:
Solve using Eq. 4.2: specific surface = surface area/
unit volume
(a) specific surface $=\frac{6\left(100 \mathrm{~mm}^{2}\right)}{10 \mathrm{~mm}^{3}}=\underline{\underline{60 / m}}$
and specific surface $=\frac{(60 / \mathrm{mm})(1000 \mathrm{~mm} / \mathrm{m})}{2.65 \mathrm{Mg} / \mathrm{m}^{3}}=22,641^{\mathrm{m}^{2}} / \mathrm{Mg}=\underline{\underline{22.6 \mathrm{~m}^{2} / \mathrm{kg}}}$
(b) specific surface $=\frac{6\left(1 \mathrm{~mm}^{2}\right)}{1 \mathrm{~mm}^{3}}=\underline{\underline{/ \mathrm{mm}}}$
and specific surface $=\frac{(6 / \mathrm{mm})(1000 \mathrm{~mm} / \mathrm{m})}{2.65 \mathrm{Mg} / \mathrm{m}^{3}}=2264 \mathrm{~m}^{2} / \mathrm{Mg}=\underline{\underline{2.26 \mathrm{~m}^{2}} / \mathrm{kg}}$
(c) specific surface $=\frac{6\left(1 \mu \mathrm{~m}^{2}\right)}{1 \mu \mathrm{~m}^{3}}=\underline{\underline{6 \mathrm{~m}}=6000 / \mathrm{mm}}$
and specific surface $=\frac{(6000 / \mathrm{mm})(1000 \mathrm{~mm} / \mathrm{m})}{2.65 \mathrm{Mg} / \mathrm{m}^{3}}=2,264,151 \mathrm{~m}^{2} / \mathrm{Mg}=\underline{\underline{2264 \mathrm{~m}^{2}} / \mathrm{kg}}$
(d) specific surface $=\frac{6\left(1 \mathrm{~nm}^{2}\right)}{1 \mathrm{~nm}^{3}}=\underline{\underline{6 / \mathrm{nm}}=6,000,000 / \mathrm{mm}}$
and specific surface $=\frac{(6,000,000 / \mathrm{mm})(1000 \mathrm{~mm} / \mathrm{m})}{2.65 \mathrm{mg} / \mathrm{m}^{3}}=2,264,151,943 \mathrm{~m}^{2} / \mathrm{Mg}=\underline{\underline{2,264,151 \mathrm{~m}^{2} / \mathrm{kg}}}$

4-2. Calculate the specific surface of (a) tennis balls, (b) ping pong balls, (c) ball bearings 1.5 mm in diameter, and (d) fly ash with approximately spherical particles 60 um in diameter.

## SOLUTION:

Solve using Eq. 4.2: specific surface = surface area/unit volume
sphere surface area $=4 \pi r^{2} ; \quad$ sphere volume $=\frac{4}{3} \pi r^{3}$
(a) tennis ball (Dia. $=67 \mathrm{~mm}$ ): specific surface $=\frac{(3)(4) \pi(67 / 2 \mathrm{~mm})^{2}}{(4) \pi(67 \mathrm{~mm} / 2)^{3}}=\underline{\underline{0.089 / \mathrm{mm}}}$
(b) ping pong ball (Dia. $=40 \mathrm{~mm}$ ): specific surface $=\frac{3}{(40 / 2)}=\underline{\underline{0.15 / \mathrm{mm}}}$
(c) ball bearings (Dia. $=1.5 \mathrm{~mm}$ ): specific surface $=\frac{3}{(1.5 / 2)}=\underline{\underline{4.0 ~ / ~ m m}}$
(d) fly ash (Dia. $=60 \mu \mathrm{~m}):$ specific surface $=\frac{3}{(60 / 2)}=\underline{\underline{0.10 / \mu \mathrm{m}=1 \times 10^{5} / \mathrm{mm}=100,000 / \mathrm{mm}}}$

4-5. Verify that the maximum and minimum void ratios for perfect spheres given in Table 4.5 are reasonable.

## SOLUTION:

Three-dimensional particle arrangement of equal spheres has been studied in depth by mathematicians, statisticians, and materials scientists since the 1600s. A quick internet search on packing of equal spheres will reveal numerous mathematical theories and approaches for estimating the densest and loosest possible packing. In general, the loosest arrangement of equal spheres yields a void fraction of about 0.48 , regardless of sphere size. The densest possible packing of equal-size spheres yields a solids volume of about: $V_{s}=\pi / \sqrt{18}=0.7405$.
(These values are approximate - there is not a unified consensus in the literature.)

## Loosest packing

For $\quad V_{t}=1.0, \quad V_{v}=0.48, \quad$ and $\quad V_{s}=1-0.48=0.52$
thus;
$\mathrm{n}_{\text {max }}=\frac{\mathrm{V}_{\mathrm{v}}}{\mathrm{V}_{\mathrm{t}}} \times 100=\frac{0.48}{1.0} \times 100=\underline{\underline{48 \%}}$
$e_{\max }=\frac{V_{v}}{V_{s}}=\frac{0.48}{0.52}=\underline{\underline{0.92}}$

Densest packing
$\mathrm{V}_{\mathrm{s}}=0.7405, \quad \mathrm{~V}_{\mathrm{v}}=1.0-0.7405=0.2595$
thus;
$n_{\text {min }}=\frac{0.2595}{1.0} \times 100=\underline{\underline{26 \%}}$
$e_{\text {min }}=\frac{0.2595}{0.7405}=\underline{\underline{0.35}}$
These agree with the values of $\mathrm{e}_{\max }$ and $\mathrm{e}_{\min }$ in Table 4.5 for equal spheres.

4-7. A specially processed clay has particles that are 500 nm thick and $10,000 \mathrm{~nm} \times 10,000 \mathrm{~nm}$ wide. The specific gravity of solids is 2.80 . The particles lie perfectly parallel with an edge-to-edge spacing of 400 nm (i.e., they look like thin bricks stacked perfectly parallel). (a) Initially, the cation valence in the double layer is +1 , resulting in a face-to-face spacing of 1500 nm . How many particles per $\mathrm{cm}^{3}$ will there be at this spacing? What are the void ratio and water content, assuming that the soil is at $100 \%$ saturation? (b) Another sample of the clay is mixed such that the cation valence is +2 . What are the new void ratio and water content under these conditions?

## SOLUTION:

Assume symmetrical edge-to-edge spacing of 400 nm and only include whole particles.
(a) no. of particles in horizontal plane along one edge $=\frac{\left(1 \times 10^{7}\right)-(2)(10,000)}{10,000+400}=959.6$
truncate and add 2 for edges $=959+2=961$
no. of particles in plan $=961 \times 961=\underline{923,521}$
no. of particles in vertical plane along one edge $=\frac{\left(1 \times 10^{7}\right)-(2)(500)}{500+1500}=4999.5$
truncate and add 2 for edges $=4999+2=\underline{5001}$
total number of particles $=923,521 \times 5001=4,618,528,521=\underline{\underline{4618.53 \times 10^{6}}}$
volume of one particle $=10,000 \times 10,000 \times 500=5.0 \times 10^{10} \mathrm{~nm}^{3}=5 \times 10^{-11} \mathrm{~cm}^{3}$
$V_{s}=4,618,528,521 \times\left(5.0 \times 10^{10}\right)=2.30926 \times 10^{20} \mathrm{~nm}^{3}=0.23093 \mathrm{~cm}^{3}$
For $S=100 \%: V_{w}=V_{v}=V_{t}-V_{s}=1-0.23093=0.7691 \mathrm{~cm}^{3} ; \quad e=\frac{V_{v}}{V_{s}}=\frac{0.7691}{0.23093}=\underline{\underline{3.33}}$
$\mathrm{M}_{\mathrm{s}}=\mathrm{G}_{\mathrm{s}} \times \mathrm{V}_{\mathrm{s}} \times \rho_{\mathrm{s}}=(2.80)(0.23093)\left(1 \mathrm{~g} / \mathrm{m}^{3}\right)=0.6466 \mathrm{~g} ; \quad \mathrm{M}_{\mathrm{w}}=\mathrm{V}_{\mathrm{w}} \times \rho_{\mathrm{w}}=(0.7691)\left(1 \mathrm{~g} / \mathrm{cm}^{3}\right)=0.7691 \mathrm{~g}$
$w=\frac{M_{w}}{M_{s}} \times 100 \%=\frac{0.7691}{0.6466} \times 100 \%=118.9=\underline{\underline{119 \%}}$
(b) assume the-face-to-face spacing doubles for a cation valence of +2
no. of particles in horizontal plane along one edge $=\frac{\left(1 \times 10^{7}\right)-(2)(10,000)}{10,000+400}=959.6$
truncate and add 2 for edges $=959+2=961$
no. of particles in plan $=961 \times 961=\underline{923,521}$ (same as part a)
no. of particles in vertical plane along one edge $=\frac{\left(1 \times 10^{7}\right)-(2)(500)}{500+3000}=2856.9$
truncate and add 2 for edges $=2856+2=\underline{2858}$
total number of particles $=923,521 \times 2858=2,639,423,018=\underline{\underline{2639.423 \times 10^{6}}}$
volume of one particle $=10,000 \times 10,000 \times 500=5.0 \times 10^{10} \mathrm{~nm}^{3}=5 \times 10^{-11} \mathrm{~cm}^{3}$
$V_{\mathrm{s}}=2,639,423,018 \times\left(5.0 \times 10^{10}\right)=1.31971 \times 10^{20} \mathrm{~nm}^{3}=0.13197 \mathrm{~cm}^{3}$
For $S=100 \%: V_{w}=V_{v}=V_{t}-V_{s}=1-0.13197=0.868 \mathrm{~cm}^{3} ; \quad e=\frac{V_{v}}{V_{s}}=\frac{0.868}{0.13197}=\underline{\underline{6.58}}$
$\mathrm{M}_{\mathrm{s}}=\mathrm{G}_{\mathrm{s}} \times \mathrm{V}_{\mathrm{s}} \times \rho_{\mathrm{s}}=(2.80)(0.13197)\left(1 \% \mathrm{~cm}^{3}\right)=0.3695 \mathrm{~g} ; \quad \mathrm{M}_{\mathrm{w}}=\mathrm{V}_{\mathrm{w}} \times \rho_{\mathrm{w}}=(0.868)\left(1 \% \mathrm{~cm}^{3}\right)=0.868 \mathrm{~g}$
$w=\frac{M_{w}}{M_{s}} \times 100 \%=\frac{0.868}{0.3695} \times 100 \%=234.9=\underline{\underline{235 \%}}$

4-15. Three sections of rock core are shown in Fig. 4.32. The rock comes from near Cumberland, RI, and is called Corbormite (Capt. James T. Kirk, personal communication, 2007). The length of the first (top) run is 56 in. and the computed RQD is $82 \%$. For the second run (middle), a length of 60 in. was recovered and the RQD is $100 \%$. Finally, the third run (bottom) is also 5 ft long and the RQD is $95 \%$. Verify that the calculated $R Q D$ values for the top and bottom runs are correct.

## SOLUTION:

RQD $=\frac{\sum \text { Length of sound pieces }>4 \text { in }}{\text { Total core run length }}$
Determine numerator values by closely examing photographs in Fig. 4.32
(a) Top run RQD $=\frac{7+9+4+8.5+8+9}{56} \times 100=\frac{45.5}{56} \times 100=\underline{\underline{81.3 \%}}$

Thus, the given value of $82 \%$ appears reasonable.
(b) Bottom run RQD $=\frac{7.5+8.5+7+11}{60} \times 100=\frac{34}{60} \times 100=\underline{\underline{57 \%}}$

The RQD value of $57 \%$ assumes all joints are natural (i.e., no mechanical breaks in this core run).
Even if all the breaks and joints shown in Fig. 4.32 are mechanical, the reported value of $95 \%$ is still too high based on the percent recovery visible in the photo.

4-16. In one core run of 1500 mm selected from cores obtained during drilling for a bridge foundation in hard limestone, the following core recovery information was obtained: Determine (a) the percent core recovery, and (b) the RQD. Based on this RQD, what is the rock quality?
\(\left.$$
\begin{array}{cc}\hline \begin{array}{c}\text { Core Recovery } \\
(\mathrm{mm})\end{array} & \begin{array}{c}\text { Length of Core Pieces } \\
>\end{array}
$$ <br>

\hline 250 \& 100 \mathrm{~mm}\end{array}\right]\)| 50 | 150 |
| :---: | :---: |
| 50 | 100 |
| 75 | 125 |
| 100 | 100 |
| 75 | 150 |
| 100 | 100 |
| 150 |  |
| 100 | Sum $=$ |
| 50 | 125 |
| Sum $=$ |  |

## SOLUTION:

(a) Core Recovery, $\mathrm{CR}=\frac{\text { Total length of rock recovered }}{\text { Total core run length }} \times 100$
$C R=\frac{250+50+50+75+100+125+75+100+150+100+50+125}{1500}=\frac{1250}{1500} \times 100=\underline{\underline{83.3 \%}}$
(b) $R Q D=\frac{\sum \text { Length of sound pieces }>100 \mathrm{~mm}}{\text { Total core run length }} \times 100$
$R Q D=\frac{150+100+125+100+150+100+125}{1500} \times 100=\frac{850}{1500} \times 100=\underline{\underline{56.7 \%}}$
Based on the Rock Mass Classifications shown in Table 4.13, the limestone rock quality would be deemed fair.

