KEY

Humans as Geomorphic Agents

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Purpose: Hooke (2000), shows us one example of how you can quantify landscape change due to human influence. We will explore the details of Hooke's calculation and get some familiarity with typical sediment transport rates for glaciers and rivers (Hallet et al., 1996).

Your first task is to read Hooke (2000) and prepare to discuss the article in class. As preparation for the discussion, get a sense of the purpose of the article, the author's methodology and results, and the implications of the results.

After class discussion, you will complete the calculations in this problem set, which will walk you through how to read a quantitative article critically. As you read other articles this semester, you should carefully examine any numbers and equations presented. Is the author internally consistent? Do the numbers match your intuition/expectations? What are the implications? Importantly, do not just take the author(s) at his/her/their word that the numbers work out!

Readings:

Hallet, B., Hunter, L., and Bogen, J., 1996, Rates of erosion and sediment evacuation by glaciers: A review of field data and their implications: Global and Planetary Change, v. 12, p. 213-235.

Hooke, R.L., 2000, On the history of humans as geomorphic agents: Geology, v. 28, p. 843-846.

Questions:

1. Hooke (2000) estimates that 115 Gt/yr (1 Gt = 10^9 t = 10^{12} kg) of earth is currently moved by humans. See Figure 4 (provided on the back page of the problem set) and be sure you can see where this number comes from. Let's compare this rate with "natural" rates of sediment transport.

   (a) Critical information (*=look up online) (0.5 pt.):

   $\left(\frac{2.69}{cm^3}\right)\left(\frac{kg}{1000 g}\right)\left(\frac{100 cm}{1 m}\right)^3 =$

   *Typical rock density = 2600 kg/m^3

   115 Gt/yr = 4.42×10^{10} m^3/yr

   Avg. radius = 6371 km = 6.371×10^6 m — *Earth's radius 6.371×10^6 m

   Earth's surface area 5.1×10^{14} m^2

   Area sphere $= 4\pi r^2 = 4\pi(6.371\times10^6 m)^2 = 5.1\times10^{14} m^2$

   Erosion rate $= \left(\frac{115 Gt}{yr}\right)\left(\frac{10^9 t}{Gt}\right)\left(\frac{1000 kg}{t}\right) = 1.15\times10^{14} \frac{kg}{yr}$

   Vol. $D = \frac{M}{Vol}$, $Vol = M/D$

   $\frac{Vol}{yr} = \frac{M/D}{t} = \frac{1.15\times10^{14} kg/yr}{2600 kg/m^3} = 4.42\times10^{10} \frac{m^3}{yr}$

(b) Suppose we took the volume of one year's worth of human sediment transport and spread it across Earth's continents. How thick would this layer be? Note that the continents cover 29% of Earth's surface. (3 pts.)

TOTAL EARTH AREA = 5.1×10^{14} m²

CONTINENTAL AREA = $(0.29)(5.1 \times 10^{14} \text{ m}^2) = 1.479 \times 10^{14} \text{ m}^2$

VOL = A · thick

$$\frac{\text{Vol Sed}}{\text{Cont Area}} = t_h = \frac{V}{A} = \frac{4.42 \times 10^{10} \text{ m}^3/\text{yr}}{1.479 \times 10^{14} \text{ m}^2} = 2.99 \times 10^{-4} \text{ m}$$

$$t = 2.99 \times 10^{-4} \text{ m} \left(\frac{1000 \text{ mm}}{\text{m}}\right) = 0.30 \text{ mm}$$

(c) Typical rates of sediment transport by glaciers and rivers are 1 mm/yr and 0.1 mm/yr, respectively (Hallet et al., 1996). Glaciers cover about 10% of Earth's continents, and we'll assume that rivers drain the remaining 90% of the continents (note: there is minimal erosion on the seafloor). Determine an expected mass of sediment transported naturally each year. (3 pts.)

$D = \frac{M}{V} = 2600 \frac{\text{kg}}{\text{m}^3}$

$M = D \cdot V$

CONTINENT AREA = 1.479×10^{14} m²

Mean rate for glaciers (kg/yr):

GLACIAL AREA = $(0.10)(1.479 \times 10^{14} \text{ m}^2) = 1.479 \times 10^{13} \text{ m}^2$

VERTICAL EROSION RATE = $1 \frac{\text{mm}}{\text{yr}} \left(\frac{1 \text{ m}}{1000 \text{ mm}}\right) = 1 \times 10^{-3}$ m

VOL ERODED = AREA · THICKNESS = $1.479 \times 10^{10} \frac{\text{m}^3}{\text{yr}} = (1.479 \times 10^{13} \text{ m}^2)\left(1 \times 10^{-3} \frac{\text{m}}{\text{yr}}\right)$

MASS = $\left(2600 \frac{\text{kg}}{\text{m}^3}\right)\left(1.479 \times 10^{10} \frac{\text{m}^3}{\text{yr}}\right)$

MASS = 3.85×10^{13} kg/yr

Mean rate for rivers (kg/yr):

RIVER AREA = $(0.90)(1.479 \times 10^{14} \text{ m}^2) = 1.33 \times 10^{14} \text{ m}^2$

VERTICAL EROSION RATE = $0.1 \frac{\text{mm}}{\text{yr}} \left(\frac{1 \text{ m}}{1000 \text{ mm}}\right) = 1 \times 10^{-4}$ m

VOL ERODED = $(1.33 \times 10^{14} \text{ m}^2)\left(1 \times 10^{-4} \frac{\text{m}}{\text{yr}}\right) = 1.33 \times 10^{10} \frac{\text{m}^3}{\text{yr}}$

MASS = $\left(2600 \frac{\text{kg}}{\text{m}^3}\right)\left(1.33 \times 10^{10} \frac{\text{m}^3}{\text{yr}}\right) = 3.458 \times 10^{13}$ kg

Total sediment transport (kg/yr):

TOTAL = GLACIAL + RIVER =

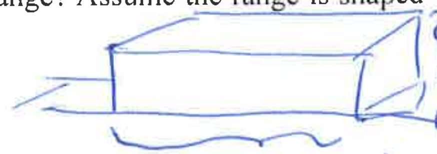
$$\left(3.85 \times 10^{13} \frac{\text{kg}}{\text{yr}}\right) + \left(3.458 \times 10^{13} \frac{\text{kg}}{\text{yr}}\right) = 7.31 \times 10^{13} \frac{\text{kg}}{\text{yr}}$$

$$7.31 \times 10^{13} \frac{\text{kg}}{\text{yr}} \left(\frac{1 \text{ Gt}}{10^{12} \text{ kg}}\right) = 73 \text{ Gt/yr}$$

RATE

2. Hooke's "Bottom Line" is that the total earth moved in the past 5000 years would be equivalent to a mountain range that is 4000 m high, 40 km wide, ~~and 100~~ km long.

(a) What is the mass of this theoretical mountain range? Assume the range is shaped like a box. Give the result in Gt. (1 pt.)



$t = 5000$ yrs

$D = \frac{M}{VOL} \Rightarrow M = D \cdot VOL$

$M = (2600 \frac{kg}{m^3})(1.6 \times 10^{13} m^3)$

$M = 4.2 \times 10^{16}$ kg $\left(\frac{1 Gt}{1 \times 10^{12} kg}\right)$

$= 4.16 \times 10^{4}$ GT

$= 4.2 \times 10^{4}$ GT

$1.6 \times 10^{13} m^3$ ← MTN VOL $= (4000 m)(40,000 m)(100,000 m)$

(b) Hooke's value comes from integrating the area under his time series of transport rates. Do this manually with a ruler for the Hooke figure, and give the final number below. Show your work on the figure on the back page. (1 pt.)

EROSION RATE $= \frac{4.2 \times 10^{4} GT}{5000 yr} = 8.32 \frac{Gt}{yr}$

(c) To get perspective on this theoretical mountain range, give us the dimensions of two North American ranges. You will need a topographic map and a ruler. Do not worry about the fact that the ranges' topography is complicated. Just use a reasonable mean width, height, and length. (0.5 pt.)

Sierra Nevada, CA: LENGTH = 600 km = 600,000 m

SEE ATTACHED CROSS SECTION

MAX RELIEF = 3100 m High

WIDTH ≅ 80 km = 80,000 m

By average

APPROX VOL $= (600,000 m)(3100 m)(80,000 m) \approx 1.5 \times 10^{14} m^3$

Wind River Range, WY:

SEE ATTACHED CROSS SECTION

58,000 ft L = 161 km = 161,000 m

145,800 ft W = 44,000 m

7500 ft ht = 2300 m

APPROX. VOL =

$(161,000 m)(44,000 m)(2300 m) =$

$\approx 1.6 \times 10^{13} m^3$

High elev = 13,800 ft
− 6000 ft

3. Based on the calculations that you have done, briefly (1-2 paragraphs) present an argument for whether or not humans have a large impact on landscapes by moving soil and rock. Consider rates of earth moving *and* the total amount of earth moved by humans versus natural processes. (1 pt)

(FROM 2b ABOVE) * HUMAN EROSION RATE LAST 5000 yrs ESTIMATED AT 8.32 $\frac{Gt}{yr}$

(FROM 1c ABOVE) * TOTAL EROSION RATE BY GLACIERS & RIVERS ≈ 73 $\frac{Gt}{yr}$

HISTORIC HUMAN RATE = $\frac{8.32 \frac{Gt}{yr}}{73 \frac{Gt}{yr}} \times 100\% = 11\%$ THE MAGNITUDE OF THAT BY RIVERS + GLACIERS COMBINED

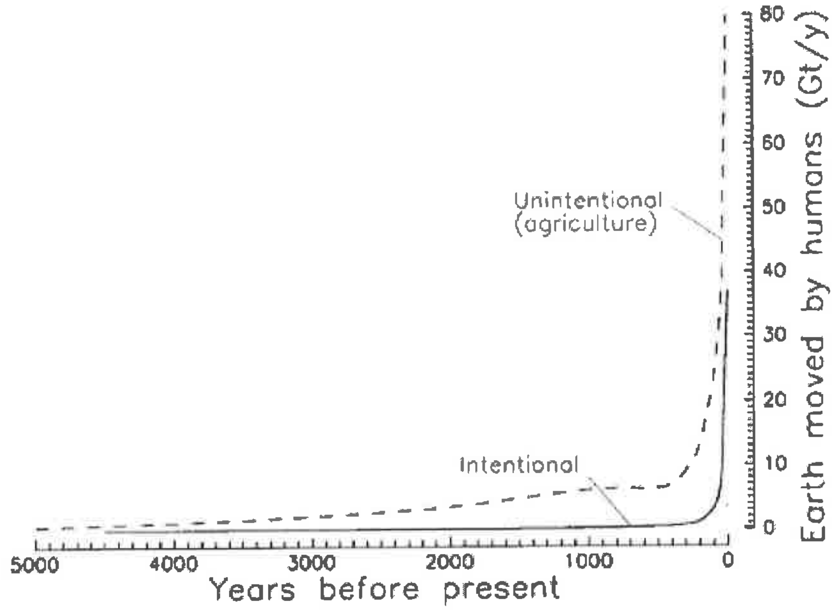


Figure 4. Estimate of total amount of earth moved annually by humans at various times in the past. Curves were obtained by multiplying earth moved per capita (Fig. 2) by population (Fig. 3).

Sierra

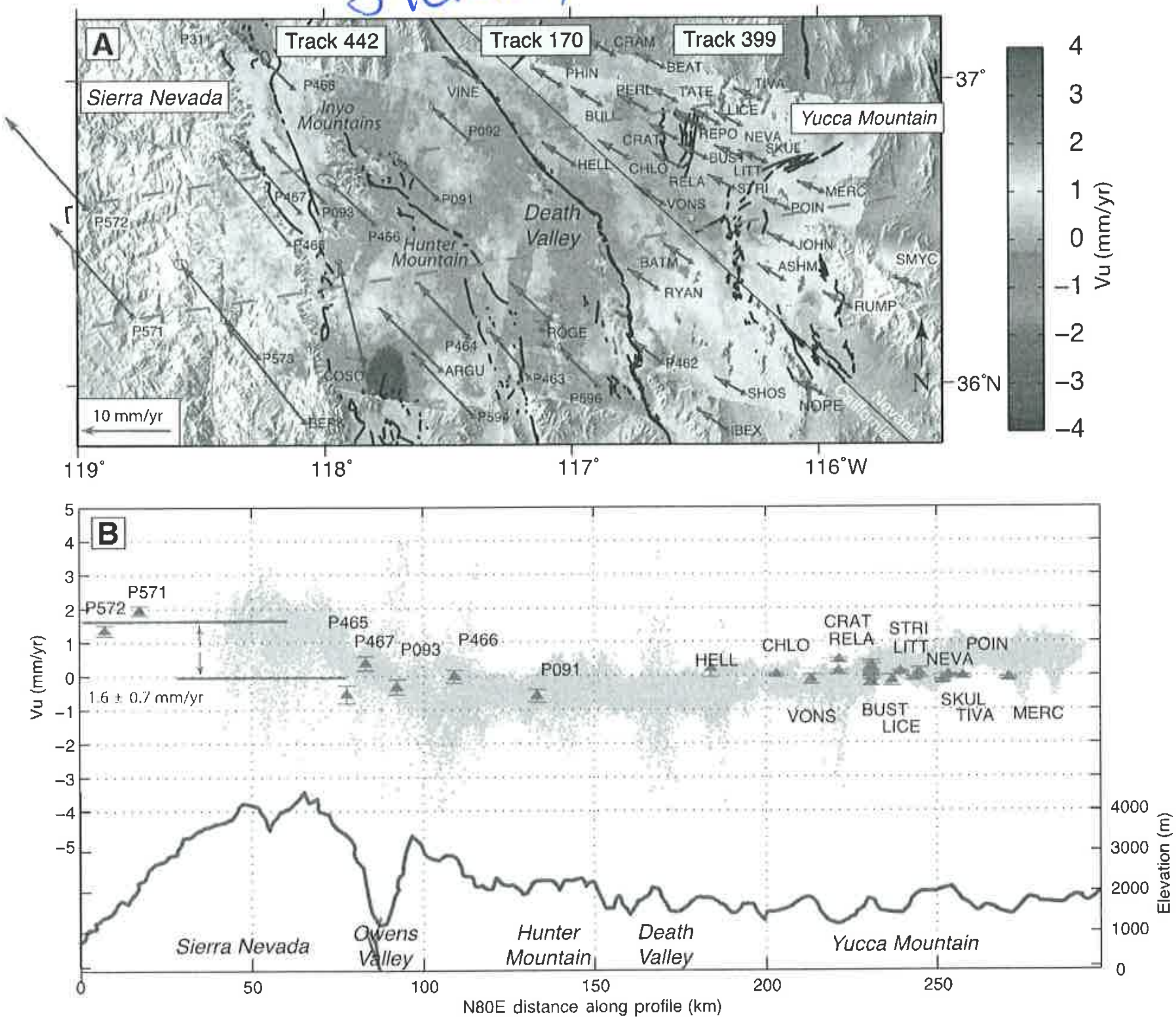


Figure 3. Upward velocity (Vu) from interferometric synthetic aperture radar (InSAR). A: Red vectors with site names show horizontal GPS velocity with respect to North America (with 95% confidence ellipses). Black lines are major faults. Dashed box indicates location of profile. B: Profile of upward rate derived from InSAR (gray) and GPS (magenta). Uncertainty bars are 2σ. Blue line indicates topography across profile. Green bars highlight mean uplift rate from InSAR. Acronyms are selected station names.

topography when relief is high, our results do not show close correlation to topography. Only the Sierra Nevada exhibits coherent uplift in both InSAR and GPS measurements, while other prominent ranges (e.g., Inyo and Panamint) do not. Third, while a lack of GPS stations in the Sierra Nevada high-country wilderness precludes direct confirmation, the InSAR is in agreement with vertical rates for stations P571 (1.9 ± 0.7 mm/yr) and P572 (1.3 ± 0.8 mm/yr), which lie immediately west of our InSAR tracks, and are corroborative because they were not used in the alignment between GPS and InSAR (Fig. 3B).

DISCUSSION AND CONCLUSIONS

Geodesy can constrain the initiation time of uplift if it measures an average motion of the solid rock valid over long periods of geologic time, adjusted for the rate of erosion (England and Molnar, 1990). An average uplift rate of 1–2 mm/yr is enough to generate ~3000 m of elevation in 1.5–3.0 m.y., assuming that erosion is negligible and that surface elevation was initially near zero. Independent estimates of Sierra Nevada erosion rates vary in space and time, between <0.01 and 0.6 mm/yr depending on whether summit bedrock or fluvial canyon incision rates are considered (Small et al., 1997; Riebe et al., 2000; Wakabayashi and Sawyer, 2001). However, geographically distributed rock uplift rates should be compared with landscape-averaged erosion rates that are likely ≤0.1 mm/yr. Thus geodetic uplift rates are much faster than erosion, indicating net uplift. If geodesy measures a recent, more rapid episode of uplift that initiated since 3.5 Ma (Clark et al., 2005), then some proportion of contemporary elevation may be ancient and could reconcile geodetic rates and data that indicate an older range.

Postglacial rebound (PGR) following the Last Glacial Maximum could also add motion unrepresentative of long-term uplift. Rates attributable to unloading following the melting of Sierra Nevada alpine glaciers are not available, but the viscoelastic rebound time scale of the adjacent Great Basin may be ~300 yr (Adams et al., 1999), implying that PGR following removal of local glaciers is complete, though the Sierra Nevada lithosphere may be stiffer, requiring more time to adjust. More recent ice

WIND RIVER

Figure 2. Mapped extent of Bull Lake ice from the Yellowstone ice cap

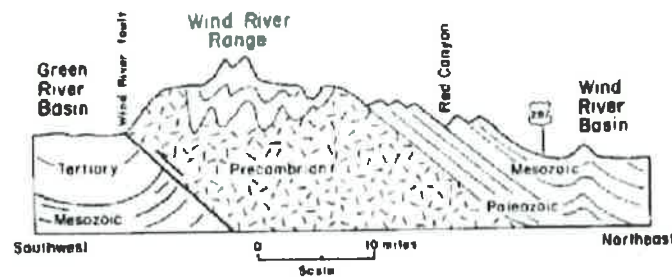


Figure 3. Generalized cross section of the Wind River Range showing the different structural relations, east vs. west. Note that the hanging wall of the Wind River Thrust buries the sedimentary rocks of the Green River Basin, whereas the sedimentary beds of the Wind River Basin are bent up into hogback formations against the Wind River massif. (From Mears et al., 1986, Courtesy of Wyoming Geological Survey)

At the base of the Fremont surface lie long, deep, glacially-carved lakes such as Fremont, New Fork, Boulder, and Willow lakes. Pleistocene till deposited by coalescent piedmont glaciers now covers a large part of the Fremont surface's lower escarpment south from Willow Lake to the East Fork drainage southeast of Boulder.

Return to U.S. Highway 191 and drive east 4.8 mi (7.7 km) to Pinedale. At 6 mi (9.7 km), as the highway swings to the right, turn left onto Fremont Lake Road. From this turn-off, the road

Name_______**KEY**_____________
Problem set 1, Geol 255, Fall 2007

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   (a) Critical information (*=look up online) (1 pt.):

*Typical rock density	___**2600**_________	kg/m^3
115 Gt/yr =	___**4.4x10^{10}**________	m^3/yr
*Earth's radius	___**6,370,000**______	m
Earth's surface area	___**5.1x10^{14}**_______	m^2

(b) Suppose we took the volume of one year's worth of human sediment transport and spread it across Earth's continents. How thick would this layer be? Note that the continents cover 29% of Earth's surface. (3 pts.)

$$\frac{4.4\times10^{10}\ m^3/yr}{(0.29)(5.1\times10^{14}\ m^2)} = 3\times10^{-4}\ m/yr = 0.3\,mm/yr$$

(c) Typical rates of sediment transport by glaciers and rivers are 1 mm/yr and 0.1 mm/yr, respectively (Hallet et al., 1996). Glaciers cover about 10% of Earth's continents, and we'll assume that rivers drain the remaining 90% of the continents (note: there is minimal erosion on the seafloor). Determine an expected mass of sediment transported naturally each year. (3 pts.)

Mean rate for glaciers (kg/yr):

$$(0.001\,m/yr)(0.1)(0.29)(5.1\times10^{14}\ m^2)(2600\ kg/m^3) = 3.8\times10^{13}\ kg/yr$$

Mean rate for rivers (kg/yr):

$$(0.0001\,m/yr)(0.9)(0.29)(5.1\times10^{14}\ m^2)(2600\ kg/m^3) = 3.5\times10^{13}\ kg/yr$$

Total sediment transport (kg/yr):

$$3.5\times10^{13}\ kg/yr + 3.8\times10^{13}\ kg/yr = 7.3\times10^{13}\ kg/yr$$

2. Hooke's "Bottom Line" is that the total earth moved in the past 5000 years would be equivalent to a mountain range that is 4000 m high, 40 km wide, and 100 km long.

   (a) What is the mass of this theoretical mountain range? Assume the range is shaped like a box. Give the result in Gt. (1 pt.)

$$\frac{(4000\ m)(40{,}000\ m)(100{,}000\ m)(2600\ kg/m^3)}{1\times 10^{12}\ kg/Gt} = 41{,}600\ Gt$$

   (b) Hooke's value comes from integrating the area under his time series of transport rates. Do this manually with a ruler for the Hooke figure, and give the final number below. Show your work on the figure on the back page. (1 pt.)

Approximate area using triangles:
Intentional: $0.5(150\ yr)(37\ Gt/yr) = 2775\ Gt$
Unintentional: $0.5(5000\ yr)(10\ Gt/yr) + 0.5(360\ yr)(70\ Gt/yr) = 37{,}600\ Gt$
Total: $2775\ Gt + 37{,}600\ Gt = 40{,}375\ Gt$
Note: this will almost certainly not match Q2a, but it should be close.

   (c) To get perspective on this theoretical mountain range, give us the dimensions of two North American ranges. You will need a topographic map and a ruler. Do not worry about the fact that the ranges' topography is complicated. Just use a reasonable mean width, height, and length. (1 pt.)

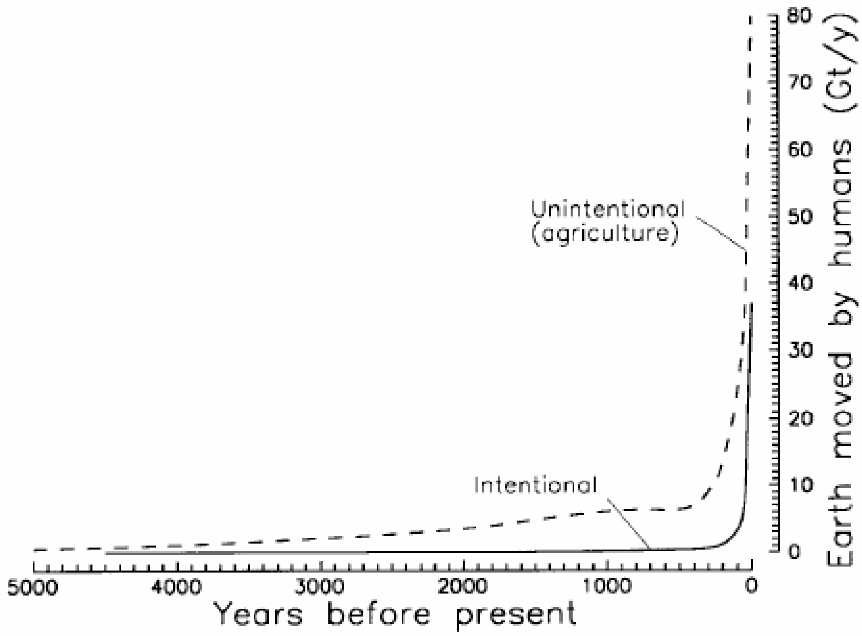
Sierra Nevada, CA:

$$(650\ km)(100\ km)(4\ km) = 260{,}000\ km^3$$

Wind River Range, WY:

$$(180\ km)(50\ km)(4\ km) = 36{,}000\ km^3$$

Note: students should realize that the Wind River Range is closer to size of Hooke's theoretical mountain range. Discuss with students whether this is an alarming or reassuring result.



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