

# Appendix C

## Answers to Selected Problems

- 1.1** 57 Myr  
**1.2** 25 km  
**1.3** 439 m  
**1.4**  $3.74 \times 10^{-4}$  T  
**1.5** 1660 km  
**1.6** 51°N, 78°E  
**1.7** 75°N, 123°E  
**1.8** 70°N, 186°E  
**1.11** 0.3°, 70°  
**1.12** 5.5°, 69°  
**1.13** 1886 km, 2441 km  
**1.14** 1028 km, 2080 km  
**1.17** 9.1 mm yr<sup>-1</sup>  
**1.18** 75 mm yr<sup>-1</sup>  
**1.19** 47 mm yr<sup>-1</sup>  
**1.20** 210°, 120 mm yr<sup>-1</sup>; 0°, 104 mm yr<sup>-1</sup>  
**1.22** 260°, 43 mm yr<sup>-1</sup>  
**1.23** 200°, 83 mm yr<sup>-1</sup>; 180°, 78 mm yr<sup>-1</sup>  
**1.24** 250°, 92.4 mm yr<sup>-1</sup>; 50 mm yr<sup>-1</sup>  
**1.25** 91°, 51 mm yr<sup>-1</sup>  
**2.1** 220 MPa  
**2.2** 68 km  
**2.3** 290 m  
**2.4** 1.18  
**2.5** 1.40  
**2.6** 5.3 km, 30 km  
**2.7** -150 MPa  
**2.9**  $4.1 \times 10^{11}$  N, 41 MPa  
**2.10**  $8.6 \times 10^4$  N  
**2.14** 166.5 MPa, -23.5 MPa  
**2.17** 4.6 GPa  
**2.18** 13,200 kg m<sup>-3</sup>, 433 GPa, 129 GPa, 12.9 m s<sup>-2</sup>  
**2.19** 47 and 63 MPa, 75° and 165°

**2.20** 0.5, 3, 5, 5.5 MPa

$$\mathbf{2.26} \quad x_c - x_a = [(x_b - x_a)^2$$

$$+ (z_b - z_a)^2]^{1/2} \frac{\sin \theta_2}{\sin(\theta_1 + \theta_2)} \\ \times \left\{ -\cos \left[ \theta_1 + \tan^{-1} \left( \frac{z_b - z_a}{x_b - x_a} \right) \right] \right\}$$

$$z_c - z_a = [(x_b - x_a)^2 + (z_b - z_a)]^{1/2} \frac{\sin \theta_2}{\sin(\theta_1 + \theta_2)} \\ \times \sin \left[ \theta_1 + \tan^{-1} \left( \frac{z_b - z_a}{x_b - x_a} \right) \right]$$

**2.27** 45 mm yr<sup>-1</sup>

**2.29** 20.2 mm/yr ( $\Delta_{PG} = 75.3^\circ$ ,  $\Delta_{PW} = 59.7^\circ$ ,  $\Delta_{GW} = 61.4^\circ$ ,  $\beta = 89.1^\circ$ )

**2.30** −85 mm/yr ( $\Delta_{PS} = 79.5^\circ$ ,  $\Delta_{PM} = 62.6^\circ$ ,  
 $\Delta_{SM} = 60.6^\circ$ ,  $\beta = 64.4^\circ$ )

**2.31** −73.8 mm/yr ( $\Delta_{PE} = 84.1^\circ$ ,  $\Delta_{PA} = 74.9^\circ$ ,  
 $\Delta_{EA} = 36.6^\circ$ ,  $\beta = 72.5^\circ$ )

**2.32** 34.5 mm/yr<sup>-1</sup>, 35.7° E of S

**2.33** 35.8 mm/yr<sup>-1</sup>, 41.9° E of S

**3.1** 180 MPa

**3.2** 42 MPa, 125 MPa

**3.3**  $v\sigma_1$ ,  $-\nu(1+\nu)\sigma_1/E$

**3.4**  $(2\nu^2 + \nu - 1)\rho gy/E$ ,  $(1 - 2\nu)\rho gy$

**3.7**  $x(L - x)M_0/2D$

**3.8**  $x(3L^2 - 4x^2)V_a/48D$

**3.9**  $q(L - x)$ ,  $-q(L - x)^2/2$

**3.10** 32.4 MPa, 0.027 MPa

**3.11**  $-x^3L \times q/12D + 3x^2L^2q/16$ ,  $0 < x < L/2(16x^4 - 64x^3L + 96x^2L^2 - 8xL^3 + L^4) \times q/384D$     $L/2 < x < L$

**3.12**  $(9Lx^2 - 4x^3)V_a/12D$     $0 < x < L/2(24Lx^2 - 8x^3 + 6L^2x - L^3)V_a/48DL/2$     $L/2 < x < L$

**3.13**  $(x^4 - 2x^3L + xL^3)q/24D$ ,  $L/2$ ,  $3L^2q/4h^2$

**3.14** 0.405 m

**3.15**  $(L^4q_0/\pi^4 D) \sin(\pi x/L)$

**3.17**  $(p - \rho gh)(L^2 - 12x^2)/24$ ,  $\pm L/2$

**3.18**  $(p - \rho gh)(12x^2 - L^2)/4h^2$ ,  $\pm L/2$

**3.20b** 1.0 GPa

**3.21** 18.1 km

**3.22** 16.5 km

**4.3** 18 ppb, 72 ppb, 0.108%

**4.4**  $7.4 \times 10^{-12} \text{ W kg}^{-1}$ ,  $3.1 \times 10^{-13} \text{ W kg}^{-1}$ ,  $1.5 \times 10^{-11} \text{ W kg}^{-1}$ ,  $1.1 \times 10^{-9} \text{ W kg}^{-1}$ ,  
 $7.7 \times 10^{-10} \text{ W kg}^{-1}$ ,  $3.4 \times 10^{-10} \text{ W kg}^{-1}$ ,  $3.5 \times 10^{-12} \text{ W kg}^{-1}$

**4.5**  $9 \times 10^{-11} \text{ W kg}^{-1}$

**4.7** 16 mW m<sup>-2</sup>, 10 km

**4.8**  $q^* = q_m + \rho h_r H^*$

**4.9** 137 km,  $0.52 \mu\text{W m}^{-3}$ 

**4.10**  $q_s = q_m + \frac{1}{2}\rho H_s b$

$$T = T_0 + \frac{1}{k} \left( q_m y + \frac{1}{2} \rho H_s b y - \frac{1}{2} \rho H_s y^2 + \frac{1}{6} \frac{\rho H_s y^3}{b} \right)$$

**4.11**  $55.5 \text{ mW m}^{-2}$ ,  $608.5^\circ\text{C}$ **4.14** 58,000 K

**4.15**  $T_0 + \frac{\rho H}{6k}(a^2 - b^2) + \Gamma b$

**4.16**  $T_0 + \frac{q_s a}{k} \left( \frac{3}{2} \frac{a}{b} - 1 \right)$

**4.17**  $T_0 + \frac{\rho H}{6k}(a^2 - r^2) + \frac{1}{3} \frac{\rho H b^3}{k} \left( \frac{1}{a} - \frac{1}{r} \right),$

$$a > r > b$$

**4.19** 733 m**4.20**  $43.8 \text{ mW m}^{-2}$ **4.23**  $1.3 \times 10^{12} \text{ yr}$ ,  $10^{11}$ ,  $3.6 \times 10^{11}$ ,  $1.2 \times 10^{12}$ ,  $1.9 \times 10^{11}$ **4.24**  $7.4 \times 10^{-15} \text{ K s}^{-1}$ **4.25**  $9.3 \times 10^{-15} \text{ K s}^{-1}$ **4.26** 3.16 m, 9.94 m**4.27** 950 m**4.28** 1.14 m**4.29**  $5.2 \times 10^{-3} \text{ K}$ 

**4.30**  $\frac{\pi}{4} + n\pi, n = 1, 2, 3 \dots$

**4.31**  $3.64(\kappa t)^{1/2}$ **4.32**  $3 \times 10^5 \text{ sec}$ 

**4.34**  $T_0 + \beta y - \Delta T_0 \operatorname{erfc} \frac{y}{2\sqrt{\kappa(t+\tau)}}, -\tau < t < 0$

$$T_0 + \beta y - \Delta T_0 \operatorname{erfc} \frac{y}{2\sqrt{\kappa(t+\tau)}} + \Delta T_0 \operatorname{erfc} \frac{y}{2\sqrt{\kappa t}}, t > 0$$

**4.37** 0.32 m**4.38** 26 Myr**4.39** 65.9 Myr, 92 km

**4.40**  $\frac{\kappa(T_m - T_0)}{(\pi\kappa t)^{1/2} \operatorname{erf} \lambda_1}, e^{\lambda_1^2}$

**4.41**  $T_0 + \frac{(T_m - T_0)}{\operatorname{erf} \lambda_3} \operatorname{erf} \left( \frac{y}{2\sqrt{\kappa t}} \right), 0 < y < y_s$

$$T_v - \frac{(T_v - T_m)}{\operatorname{erfc} \lambda_3} \operatorname{erfc} \left( \frac{y - y_s}{2\sqrt{\kappa t}} \right), y > y_s$$

$$\frac{(T_m - T_v)}{\operatorname{erfc} \lambda_3} - \frac{(T_v - T_m)}{\operatorname{erfc} \lambda_3} = \frac{\sqrt{\pi} L \lambda_3 e^{\lambda_3^2}}{c}$$

**4.42** 32 km

- 4.43** 140 km  
**4.44** 1.29 days  
**4.46**  $T_0 + (T_\infty - T_0) \exp\left(-\frac{U\xi}{\kappa}\right)$   
**4.47** 
$$\frac{T_0 - T_\infty \operatorname{erf}(\alpha/2\sqrt{\kappa})}{1 - \operatorname{erf}(\alpha/2\sqrt{\kappa})}$$
$$+ \left[ \frac{T_\infty - T_0}{1 - \operatorname{erf}(\alpha/2\sqrt{\kappa})} \right] \operatorname{erf} \frac{y}{2\sqrt{\kappa t}}$$
  
**4.48**  $\frac{q_m}{\rho[L + c(T_m - T_0)]}$   
**4.49** 16.5 MPa  
**4.50** 6.4 km  
**4.52** 500 m, 200 m  
**4.53** 0.04 mm yr<sup>-1</sup>  
**4.54**  $\frac{\chi(\rho_m - \rho_l)y_L}{(\rho_m - \rho_w)}, 0.6$   
**4.55** 320 m  
**4.56** 4.2 km  
**4.57** 2–3 km  
**4.58** 7.6 km, 12.8 km  
**4.59** 10.6 km, 18.5 km  
**4.60** 2.46 km  
**4.61** 68 K  
**4.62** 17,000 K  
**4.63** 2.7 K  
**4.67**  $7.1 \times 10^{-7} \text{ m}^2 \text{ s}^{-1}$   
**4.68**  $2.3 \times 10^{-10} \text{ m}^2 \text{ s}^{-1}$   
**5.1**  $1.67 \times 10^{-3}$   
**5.2**  $3.4621 \times 10^{-3}$   
**5.3** (a)  $6.25 \times 10^7 \text{ J}$ , (b)  $1.12 \times 10^4 \text{ m s}^{-1}$ ,  
(c) 62,200 K  
**5.4** No  
**5.5**  $9.78031846 \text{ m s}^{-2}, 9.832177 \text{ m s}^{-2},$   
 $9.7804629 \text{ m s}^{-2}, 9.832011 \text{ m s}^{-2}$   
**5.7**  $g_e + 2Gb/a^3$   
**5.8**  $4140 \text{ kg m}^{-3}, 12,410 \text{ kg m}^{-3}$   
**5.9**  $4460 \text{ kg m}^{-3}$   
**5.10** 3.74 days  
**5.11** 21 hours  
**5.12** 13 million tons  
**5.16**  $3.98 \text{ mm s}^{-2}$   
**5.18** 8.1 km  
**5.19**  $4.3 \times 10^6 \text{ kg m}^{-2}$   
**5.20**  $0.044978 \text{ mm s}^{-2}, -0.56184 \text{ mm s}^{-2}$

**5.22**  $\frac{\pi G}{g} \rho_{cu} \left\{ 2h \left[ H + \left( \frac{\rho_m - \rho_{cl}}{\rho_m - \rho_{cu}} \right) b_L \right] + \frac{h^2 \rho_m}{(\rho_m - \rho_{cu})} \right\}$

**5.23** 14.4 km

**6.2**  $\frac{1}{2} \frac{dp}{dx} (2y - h) - \mu \frac{u_0}{h}, -\mu \frac{u_0}{h}, \frac{1}{2} \frac{dp}{dx} (2y - h)$

**6.3**  $\frac{h}{2} + \frac{\mu_0 u_0}{h(dp/dx)}$

**6.4**  $\frac{\rho g h^2 \sin \alpha}{3\mu}, \left( \frac{3\mu Q}{\rho g \sin \alpha} \right)^{1/3}$

**6.5** 0.317 MPa

**6.6** 19.2 MPa

**6.7**  $1.27 \times 10^{-20}$

**6.8** 0.025 m,  $0.84 \text{ m s}^{-1}$ ,  $4 \times 10^4$

**6.9**  $(\rho_s - \rho_l)gd^3/12\mu$

**6.10**  $-\frac{1}{2\mu} \frac{dp}{dx} \left( \frac{y^3}{3} - \frac{hy^2}{2} \right) + \frac{u_0 y^2}{2h} - u_0 y,$

$$-u_0 \left[ y - \frac{y^2}{2h} + 6 \left( \frac{h_L}{h} + \frac{1}{2} \right) \left( \frac{y^3}{3h^2} - \frac{y^2}{2h} \right) \right]$$

**6.12** 0.61 km, 0.22 km,  $4 \times 10^{21}$  Pa s

**6.13**  $u = \frac{-\sqrt{2}U}{(2 - \frac{\pi^2}{4})} \left[ \frac{\pi}{2} + \left( \frac{\pi}{2} - 2 \right) \tan^{-1} \frac{y}{x} - \left( \frac{\pi x}{2} + \left[ 2 - \frac{\pi}{2} \right] y \right) \left( \frac{x}{x^2 + y^2} \right) \right]$

$$v = \frac{-\sqrt{2}U}{(2 - \frac{\pi^2}{4})} \left[ \frac{\pi}{2} \tan^{-1} \frac{y}{x} - \left( \frac{\pi x}{2} + \left[ 2 - \frac{\pi}{2} \right] y \right) \left( \frac{y}{x^2 + y^2} \right) \right]$$

$$\begin{aligned} u &= \frac{U}{(\frac{9\pi^2}{4} - 2)} \left\{ \left( \frac{9\pi^2}{4} - 2 \right) + \pi(2\sqrt{2} - 3\pi) \right. \\ &\quad \left. - \left[ \sqrt{2} \left( 2 + \frac{3\pi}{2} \right) - 2 \left( 1 + \frac{3\pi}{2} \right) \right] \tan^{-1} \frac{x}{y} - \left[ \left( 2 - \sqrt{2} \frac{3\pi}{2} \right) x \right. \right. \\ &\quad \left. \left. + \left( \sqrt{2} \left[ 2 + \frac{3\pi}{2} \right] - 2 \left[ 1 + \frac{3\pi}{2} \right] \right) y \right] \right. \\ &\quad \left. \times \frac{x}{x^2 + y^2} \right\} \end{aligned}$$

$$\begin{aligned} v &= \frac{U}{(\frac{9\pi^2}{4} - 2)} \left\{ \left( 2 - \sqrt{2} \frac{3\pi}{2} \right) \pi + \left( 2 - \sqrt{2} \frac{3\pi}{2} \right) \tan^{-1} \frac{y}{x} \right. \\ &\quad \left. - \left[ \left( 2 - \sqrt{2} \frac{3\pi}{2} \right) x + \left( \sqrt{2} \left( 2 + \frac{3\pi}{2} \right) \right. \right. \right. \\ &\quad \left. \left. \left. - 2 \left[ 1 + \frac{3\pi}{2} \right] \right) y \right] \frac{x}{x^2 + y^2} \right\} \end{aligned}$$

**6.15**  $4.6 \times 10^{18}$  Pa s

**6.16** 195,000 yr

**6.20**  $3.3 \times 10^{18}$  Pa s

**6.21**  $8.46 \times 10^{20} \text{ Pa s}$

**6.24** 52 km,  $55 \text{ m}^3 \text{ s}^{-1}$ ,  $4.6 \times 10^{10} \text{ W}$ ,  $0.21 \text{ m yr}^{-1}$ ,  $1.38 \times 10^8 \text{ km}^3$

**6.25** 74 km,  $232 \text{ m}^3 \text{ s}^{-1}$ ,  $1.9 \times 10^{11} \text{ W}$ ,  $0.42 \text{ m yr}^{-1}$ ,  $2.22 \times 10^9 \text{ km}^3$

**6.26**  $T = C_1x + C_2 + \frac{C_1}{4\kappa\mu} \left( \frac{1}{6}y^4 - \frac{1}{4}d^2y^2 + \frac{5}{96}d^4 \right)$

$$q = \frac{C_1kd^3}{24\kappa\mu}, h = \frac{70}{17} \frac{k}{d}, \text{ Nu} = \frac{70}{17}$$

**6.29**  $2.4 \times 10^5, 2.9 \times 10^9, 4.2 \times 10^7, 1.2 \times 10^6$

**6.30** 1.16 b, 7.85 b

**6.33** 14.4 km

**6.35** 0.32

**6.38**  $T_0 + \frac{\mu u_0^2}{kh^2} \left( hy - \frac{1}{2}y^2 \right), \frac{\mu u_0^2}{h}, \frac{\mu u_0^2}{2, k}$

**7.1** 547 kJ mol<sup>-1</sup>

**7.3**  $1.6 \times 10^8 \text{ Pa}$

**7.4**  $1.24 \times 10^3 \text{ J kg}^{-1} \text{ K}^{-1}$

**7.11** -72 bar

**7.13** 137 MPa, 860 K

**7-21**  $\sigma^*, \sigma^*/\sqrt{6}$

**7.18**  $\frac{\sigma_0}{E}, \frac{\sigma_0}{E} + \frac{\sigma_0 t}{2\mu}, \frac{\sigma_0 t}{2\mu}$

**7.22**  $\sigma_0/[(1-\nu)^2 + 1]^{1/2}, (1-\nu^2)\sigma_0/E[(1-\nu)^2 + \nu]^{1/2}$

**7.23**  $2\tau, \sqrt{3}\tau$

**7.24**  $2\pi\sigma_0 \left( \frac{a^3}{3} - \frac{c^3}{12} \right), \frac{\pi\sigma_0 a^3}{2}, \frac{2\pi\sigma_0 a^3}{3}$

**8.1**  $38.7^\circ$

**8.5** 2

**8.8**  $3.55 \times 10^{17} \text{ J}, 0.025\%$