1. **Esercizio**

**1. Utilizzare i valori di porosità iniziale (*0*) per calcolare la conduttività termica con le due equazioni sottostanti (geometric mean e square root mean) in ciascuno strato di una stratigrafia così composta:**

Sand: 1300 m (depth), 35% (*0*), 1.79 W/mK (conductivity)

Siltstone: 3500 m(depth) 30% (*0*), 1.58 W/mK (conductivity)

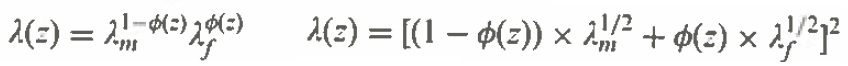
Clay: 4800 m (depth) 25% (*0*), 1.43 W/mK (conductivity)

Marl: 7200 m (depth) 15% (*0*), 1.68 W/mK (conductivity)

Limestone: 10000 m (depth) 25% (*0*), 2.37 W/mK (conductivity)

Factor *b* is 0.180 and 0.396 km-1 in carbonate rocks, 0.298 and 0.461 km-1 in marls and silty marls, 0.284 and 0.216 km-1 in sandstones and calcarenites, and 0.293 and 0.379 km-1 in shales and siltstones.

(per la stima della porosità z è in km se b è in km)



(geometric mean) (square root mean)

*Kw* = 0.6 W/mK

1. **Fare un plot dei valori di conduttività termica ottenuti in funzione della profondità.**
2. **Calcolare il valore medio di conduttività termica della formazione sedimentaria applicando una media armonica (usata nel caso di una stratificazione orizzontale).**



%esercizio1

%conduttivita' termica per stratigrafia

% 5 strati

clear all

kw=0.6;% %W/mK CONDUCTIVITY water

%strato1 sand

d(1,1)=0; d(1,2)=1.300;% depth

phi(1)=0.35; % porosity

km(1)=1.79; %W/mK CONDUCTIVITY matrix

% strato 2 Siltstone

d(2,1)=1.3; d(2,2)=3.500;% depth

phi(2)=0.30; % porosity

km(2)=1.58; %W/mK CONDUCTIVITY matrix

b(2)=0.379; % decay factor porosity km^-1

% strato 3 Clay

d(3,1)=3.5; d(3,2)=4.800;% depth

phi(3)=0.25; % porosity

km(3)=1.88; %W/mK CONDUCTIVITY matrix

b(3)=0.293; % decay factor porosity km^-1

% strato 4 Marl

d(4,1)=4.8; d(4,2)=7.2;% depth

phi(4)=0.15; % porosity

km(4)=1.68; %W/mK CONDUCTIVITY matrix

b(4)=0.298; % decay factor porosity km^-1

% strato 5 Limestone

d(5,1)=7.2; d(5,2)=10.;% depth

phi(5)=0.40; % porosity

km(5)=2.37; %W/mK CONDUCTIVITY matrix

b(5)=0.396; % decay factor porosity km^-1

figure

hold on

for i=1:5

z(i,:)=linspace(d(i,1),d(i,2),10);

zstrato=z(i,:);

phiz=phi(i)\*exp(-b(i).\*zstrato); % porosita' in funzione depth

k=km(i).^(1-phiz).\*kw.^phiz;

kmedio(i)=mean(k);

plot(z(i,:),k)

xlabel('z (km)'); ylabel('k (W/mK)');

end

% Conduttivita' termica media come media armonic

perc=(d(:,2)/10);

prod=(1./kmedio').\*perc

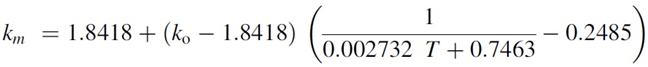
kmed=sum(prod)

title(['conductivity sand-siltstone-clay-marl-Limestone. kmed= ' num2str(kmed)])

**Esercizio 2**

1. **Costruire una geoterma nei primi 10 km usando un gradiente che varia da 30°C/km (a 0 km) a 21C°/km (a 10 km). Ripetere il primo esercizio considerando la dipendenza della conduttività dalla temperatura usando le equazioni sottostanti per la conduttività termica della matrice e dell’acqua presente nei pori.**

Condizione iniziale: T0 (0 km) =0; T1 (1 km) = 30°C

g

for T> 137°C

for T≤ 137°C

Kw= 0.6020 +1.309 x 10-3 *T* -5.140 x 10-6 *T2*

1. **Fare un plot dei valori di conduttività termica ottenuti in funzione della profondità.**
2. **Calcolare il valore medio di conduttività termica della formazione sedimentaria, applicando una media armonica (usata nel caso di una stratificazione orizzontale).**

****

%esercizio2

%conduttivita' termica per stratigrafia e dipende da Temperatura

% 5 strati in input e geoterma

clear all

kw=0.6;% %W/mK CONDUCTIVITY water

%strato1 sand

d(1,1)=0; d(1,2)=1.300;% depth

phi(1)=0.35; % porosity

km(1)=1.79; %W/mK CONDUCTIVITY matrix

% strato 2 Siltstone

d(2,1)=1.3; d(2,2)=3.500;% depth

phi(2)=0.30; % porosity

km(2)=1.58; %W/mK CONDUCTIVITY matrix

b(2)=0.379; % decay factor porosity km^-1

% strato 3 Clay

d(3,1)=3.5; d(3,2)=4.800;% depth

phi(3)=0.25; % porosity

km(3)=1.88; %W/mK CONDUCTIVITY matrix

b(3)=0.293; % decay factor porosity km^-1

% strato 4 Marl

d(4,1)=4.8; d(4,2)=7.2;% depth

phi(4)=0.15; % porosity

km(4)=1.68; %W/mK CONDUCTIVITY matrix

b(4)=0.298; % decay factor porosity km^-1

% strato 5 Limestone

d(5,1)=7.2; d(5,2)=10.;% depth

phi(5)=0.40; % porosity

km(5)=2.37; %W/mK CONDUCTIVITY matrix

b(5)=0.396; % decay factor porosity km^-1

% calcolo isoterma

%a z=0 dT/dz=30°C/km decrescente a 21°C/km a 10km

T0=0; % temperatura a superficie z=0

n=50; % numero passo

dz=12/n;

T(1)=0;

zT(1)=0;

for i=2:n

zT(i)=zT(1)+(i-1)\*dz;

dT\_dz(i)=30+(21-30)/10\*(i-1)\*dz;

T(i)=dT\_dz(i)\*dz+T(i-1);

end

figure

subplot(1,2,1);

plot(zT,T)

xlabel('z (km)'); ylabel('T (°C)');

title(['Geothermal curve'])

%figure

subplot(1,2,2);

hold on

nz=10;

for i=1:5

z(i,:)=linspace(d(i,1),d(i,2),nz);

zstrato=z(i,:); % zstrato e' riga

Tint=interp1(zT,T,zstrato);

for j=1:nz

phiz(j)= phi(i)\*exp(-b(i)\*zstrato(j)) ; % porosita' in funzione depth

% kmT(i,j): correzione di km per la temperatura(j)

kmT(i,j)=1.8418+(km(i)-1.8418)\*((0.002732\*Tint(j)+0.7463)^-1-0.2485);

% kwT(i,j): correzione di kw per la temperatura(j)

if Tint(j) <= 137

kwT(i,j)=0.5648+1.878\*0.001\*Tint(j);

else

kwT(i,j)=0.6020+1.309\*0.001\*Tint(j)-5.140\*10^-6\*Tint(j)^2;

end

kT(i,j)=kmT(i,j)^(1-phiz(j))\*kwT(i,j)^phiz(j);

end % end calculating parameters in function of depth

kmedio(i)=mean(kT(i,:));

plot(z(i,:),kT(i,:))

xlabel('z (km)'); ylabel('k(T) (W/mK)');

end

% Conduttivita' termica media come media armonic

perc=(d(:,2)/10);

prod=(1./kmedio').\*perc

kmed=sum(prod)

title(['conductivity Temp.-corrected.kmed= ' num2str(kmed)])

%

**Esercizio 3**

1. **Calcolare la conduttività termica reticolare e radiativa (e la loro somma) con le equazioni di Hasterock e Chapman (2011), usando la geoterma in Tab. 4 e la pressione in Tab. 3, per una olivina contenente il 90% di forsterite.**
2. **Fare un plot dei valori di conduttività termica ottenuti in funzione della temperatura.**

****

**Didascalia: nella figura klattice, la curva blue rappresenta klattice, quella rossa la somma fra klattice e kradiativo.**

%esercizio3

%conduttivita' reticolare e radiativa in funzione della temperatura

% pressione e geoterma data da tabella

% roccia: olivina contenente il 90% di forsterite.

clear all

zT=load('Geoterma\_Es3.txt');

zP=load('Pressione\_profondita.txt');

nT=length(zT(:,1)); nP=length(zP(:,1));

figure

subplot(2,2,1)

plot(zT(:,1),zT(:,2))

xlabel('z (km)'); ylabel('T (°C)');

subplot(2,2,2)

plot(zP(:,1),zP(:,2))

xlabel('z (km)'); ylabel('P (GPa)');

%depth

for i=1:nT

% define pressure for given Temperature value

P=interp1(zP(:,1),zP(:,2),zT(i,1));

% km lattice conductivity

chi=0.9 %mole fraction of fosterite for the olivine rock

n=0.49

lam\_m=3.09-1.17\*chi %3.09 conduct of olivine, 1.17 of fosterite

Kt=128 % GPa

Ktgrd=4.2 %pressure gradient of Kt

TKelv=zT(i,2)+273.15;

km(i)=lam\_m \* (298/TKelv)^n \* (1 + Ktgrd/Kt\*P );

% kr radiative conductivity

% erf Error function.

% Y = erf(X) is the error function for each element of X. X must be

% real. The error function is defined as:

%

% erf(x) = 2/sqrt(pi) \* integral from 0 to x of exp(-t^2) dt.

lam\_r= 0.345; % W/m/K maximum radiative conductivity

Tr= 762; %K temperature at 0.5 lam\_r

om= 256; % K scaling factor

kr(i)=0.5\*lam\_r\*(1+ erf((TKelv-Tr)/om) );

end

subplot(2,2,3)

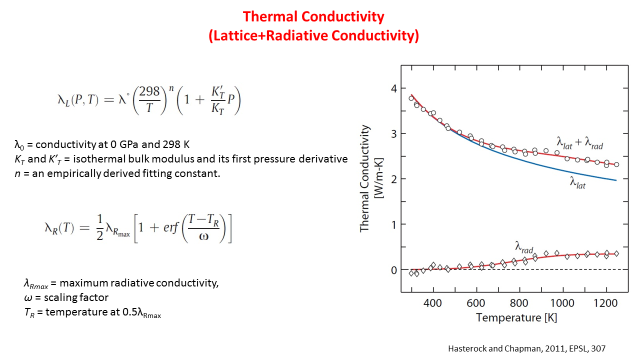
plot(zT(:,2),km,zT(:,2),km+kr) %

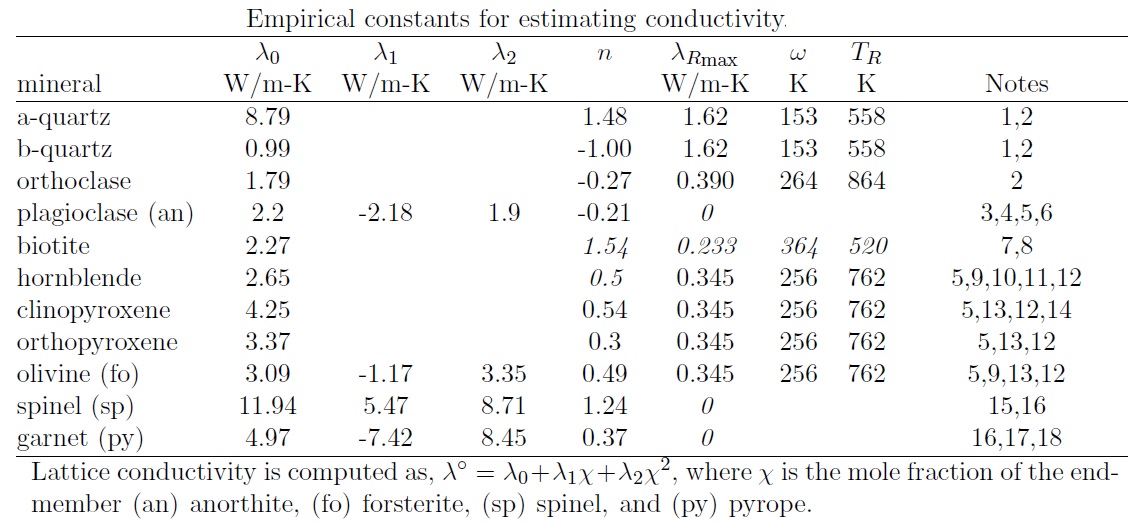
xlabel('T (°C)'); ylabel('klattice (W/mK)');

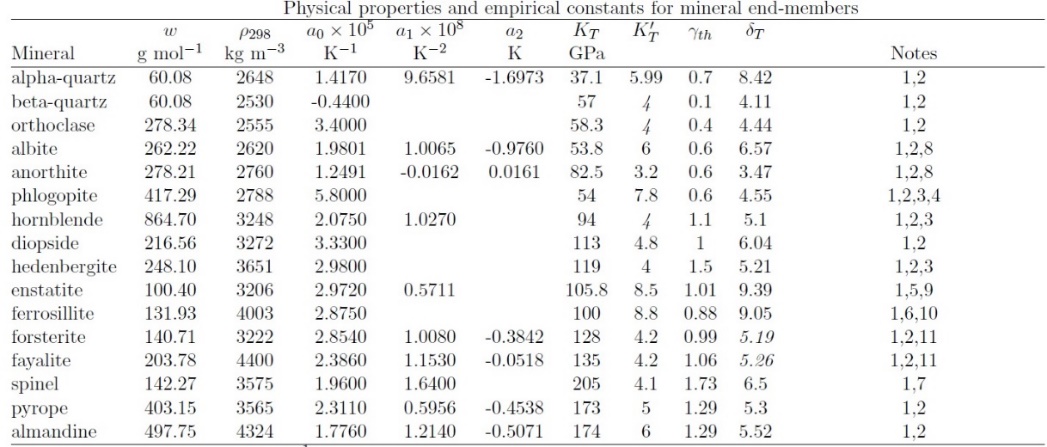
subplot(2,2,4)

plot(zT(:,2),kr) %

xlabel('T (°C)'); ylabel('kradiative (W/mK)');

****





|  |  |
| --- | --- |
| Depth (km) | Pressure (GPa) |
| 0 | 0 |
| 3.5 | 0.1 |
| 35 | 1 |
| 50 | 1.45 |
| 75 | 2.285 |
| 100 | 3.115 |
| 125 | 3.945 |
| 150 | 4.78 |

**Tab. 3 Pressure vs Depth**

|  |  |
| --- | --- |
| Depth (km) | T (°C) |
| 0 | 0 |
| 0.5 | 7.25 |
| 1 | 14.5 |
| 1.5 | 21.75 |
| 2 | 29 |
| 2.5 | 36.25 |
| 3 | 43.5 |
| 3.5 | 50.75 |
| 4 | 58 |
| 4.5 | 65.25 |
| 5 | 72.5 |
| 5.5 | 79.75 |
| 6 | 87 |
| 6.5 | 94.25 |
| 7 | 101.5 |
| 7.5 | 108.75 |
| 8 | 116 |
| 8.5 | 123.25 |
| 9 | 130.5 |
| 9.5 | 137.75 |
| 10 | 145 |
| 10.5 | 151.5 |
| 11 | 158 |
| 11.5 | 164.5 |
| 12 | 171 |
| 12.5 | 177.5 |
| 13 | 184 |
| 13.5 | 190.5 |
| 14 | 197 |
| 14.5 | 203.5 |
| 15 | 210 |
| 15.5 | 216.5 |
| 16 | 223 |
| 16.5 | 229.5 |
| 17 | 236 |
| 17.5 | 242.5 |
| 18 | 249 |
| 18.5 | 255.5 |
| 19 | 262 |
| 19.5 | 268.5 |
| 20 | 275 |
| 20.5 | 280.75 |
| 21 | 286.5 |
| 21.5 | 292.25 |
| 22 | 298 |
| 22.5 | 303.75 |
| 23 | 309.5 |
| 23.5 | 315.25 |
| 24 | 321 |
| 24.5 | 326.75 |
| 25 | 332.5 |
| 25.5 | 338.25 |
| 26 | 344 |
| 26.5 | 349.75 |
| 27 | 355.5 |
| 27.5 | 361.25 |
| 28 | 367 |
| 28.5 | 372.75 |
| 29 | 378.5 |
| 29.5 | 384.25 |
| 30 | 390 |
| 30.5 | 395.75 |
| 31 | 401.5 |
| 31.5 | 407.25 |
| 32 | 413 |
| 32.5 | 416 |
| 33 | 420 |
| 33.5 | 424 |
| 34 | 428 |
| 34.5 | 432 |
| 35 | 436 |
| 35.5 | 440 |
| 36 | 444 |
| 36.5 | 448 |
| 37 | 452 |
| 37.5 | 456 |
| 38 | 460 |
| 38.5 | 464 |
| 39 | 468 |
| 39.5 | 472 |
| 40 | 476 |
| 40.5 | 480 |
| 41 | 484 |
| 41.5 | 488 |
| 42 | 492 |
| 42.5 | 496 |
| 43 | 500 |
| 43.5 | 504 |
| 44 | 508 |
| 44.5 | 512 |
| 45 | 516 |
| 45.5 | 520 |
| 46 | 524 |
| 46.5 | 528 |
| 47 | 532 |
| 47.5 | 536 |
| 48 | 540 |
| 48.5 | 544 |
| 49 | 548 |
| 49.5 | 552 |
| 50 | 556 |
| 50.5 | 560 |
| 51 | 564 |
| 51.5 | 568 |
| 52 | 572 |
| 52.5 | 576 |
| 53 | 580 |
| 53.5 | 584 |
| 54 | 588 |
| 54.5 | 592 |
| 55 | 596 |
| 55.5 | 600 |
| 56 | 604 |
| 56.5 | 608 |
| 57 | 612 |
| 57.5 | 616 |
| 58 | 620 |
| 58.5 | 624 |
| 59 | 628 |
| 59.5 | 632 |
| 60 | 636 |
| 60.5 | 640 |
| 61 | 644 |
| 61.5 | 648 |
| 62 | 652 |
| 62.5 | 656 |
| 63 | 660 |
| 63.5 | 664 |
| 64 | 668 |
| 64.5 | 672 |
| 65 | 676 |
| 65.5 | 680 |
| 66 | 684 |
| 66.5 | 688 |
| 67 | 692 |
| 67.5 | 696 |
| 68 | 700 |
| 68.5 | 704 |
| 69 | 708 |
| 69.5 | 712 |
| 70 | 716 |
| 70.5 | 720 |
| 71 | 724 |
| 71.5 | 728 |
| 72 | 732 |
| 72.5 | 736 |
| 73 | 740 |
| 73.5 | 744 |
| 74 | 748 |
| 74.5 | 752 |
| 75 | 756 |
| 75.5 | 760 |
| 76 | 764 |
| 76.5 | 768 |
| 77 | 772 |
| 77.5 | 776 |
| 78 | 780 |
| 78.5 | 784 |
| 79 | 788 |
| 79.5 | 792 |
| 80 | 796 |
| 80.5 | 800 |
| 81 | 804 |
| 81.5 | 808 |
| 82 | 812 |
| 82.5 | 816 |
| 83 | 820 |
| 83.5 | 824 |
| 84 | 828 |
| 84.5 | 832 |
| 85 | 836 |
| 85.5 | 840 |
| 86 | 844 |
| 86.5 | 848 |
| 87 | 852 |
| 87.5 | 856 |
| 88 | 860 |
| 88.5 | 864 |
| 89 | 868 |
| 89.5 | 872 |
| 90 | 876 |
| 90.5 | 880 |
| 91 | 884 |
| 91.5 | 888 |
| 92 | 892 |
| 92.5 | 896 |
| 93 | 900 |
| 93.5 | 904 |
| 94 | 908 |
| 94.5 | 912 |
| 95 | 916 |
| 95.5 | 920 |
| 96 | 924 |
| 96.5 | 928 |
| 97 | 932 |
| 97.5 | 936 |
| 98 | 940 |
| 98.5 | 944 |
| 99 | 948 |
| 99.5 | 952 |
| 100 | 956 |
| 100.5 | 960 |
| 101 | 964 |
| 101.5 | 968 |
| 102 | 972 |
| 102.5 | 976 |
| 103 | 980 |
| 103.5 | 984 |
| 104 | 988 |
| 104.5 | 992 |
| 105 | 996 |
| 105.5 | 1000 |
| 106 | 1004 |
| 106.5 | 1008 |
| 107 | 1012 |
| 107.5 | 1016 |
| 108 | 1020 |
| 108.5 | 1024 |
| 109 | 1028 |
| 109.5 | 1032 |
| 110 | 1036 |
| 110.5 | 1040 |
| 111 | 1044 |
| 111.5 | 1048 |
| 112 | 1052 |
| 112.5 | 1056 |
| 113 | 1060 |
| 113.5 | 1064 |
| 114 | 1068 |
| 114.5 | 1072 |
| 115 | 1076 |
| 115.5 | 1080 |
| 116 | 1084 |
| 116.5 | 1088 |
| 117 | 1092 |
| 117.5 | 1096 |
| 118 | 1100 |
| 118.5 | 1104 |
| 119 | 1108 |
| 119.5 | 1112 |
| 120 | 1116 |
| 120.5 | 1120 |
| 121 | 1124 |
| 121.5 | 1128 |
| 122 | 1132 |
| 122.5 | 1136 |
| 123 | 1140 |
| 123.5 | 1144 |
| 124 | 1148 |
| 124.5 | 1152 |
| 125 | 1156 |
| 125.5 | 1160 |
| 126 | 1164 |
| 126.5 | 1168 |
| 127 | 1172 |
| 127.5 | 1176 |
| 128 | 1180 |
| 128.5 | 1184 |
| 129 | 1188 |
| 129.5 | 1192 |
| 130 | 1196 |
| 130.5 | 1200 |
| 131 | 1204 |
| 131.5 | 1208 |
| 132 | 1212 |
| 132.5 | 1216 |
| 133 | 1220 |
| 133.5 | 1224 |
| 134 | 1228 |
| 134.5 | 1232 |
| 135 | 1236 |
| 135.5 | 1240 |
| 136 | 1244 |
| 136.5 | 1248 |
| 137 | 1252 |
| 137.5 | 1256 |
| 138 | 1260 |
| 138.5 | 1264 |
| 139 | 1268 |
| 139.5 | 1272 |
| 140 | 1276 |
| 140.5 | 1280 |
| 141 | 1284 |
| 141.5 | 1288 |
| 142 | 1292 |
| 142.5 | 1296 |
| 143 | 1300 |
| 143.5 | 1304 |
| 144 | 1308 |
| 144.5 | 1312 |
| 145 | 1316 |
| 145.5 | 1320 |
| 146 | 1324 |
| 146.5 | 1328 |
| 147 | 1332 |
| 147.5 | 1336 |
| 148 | 1340 |
| 148.5 | 1344 |
| 149 | 1348 |
| 149.5 | 1352 |
| 150 | 1356 |

**Tab.4 Temperature vs Depth**

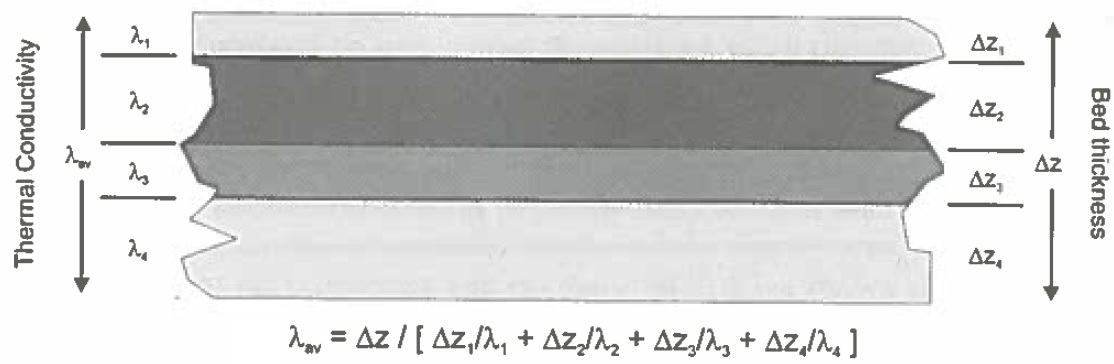
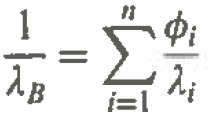
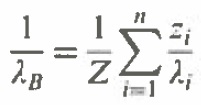
**Appendix: Harmonic Mean**

**i= thermal conductivity of *i*th bed**

****i=fractional proportion**

***zi*=thickness of the *i*th bed**

**Z=total thickness of sequence**



**i= thermal conductivity of *i*th bed**

****i=fractional proportion**

***zi*=thickness of the *i*th bed**

**Z=total thickness of sequence**