



Geofyzikálny ústav Slovenskej akadémie vied



# **Refrakcia tepelného toku na kontrastných podpovrchových štruktúrach - vplyv na merania a interpretačné prístupy**

(Heat flow refraction on subsurface contrast structures - the influence both on measurements and on interpretation approaches)

**Dušan MAJCIN, Dušan BILČÍK, Milan HVOŽDARA**

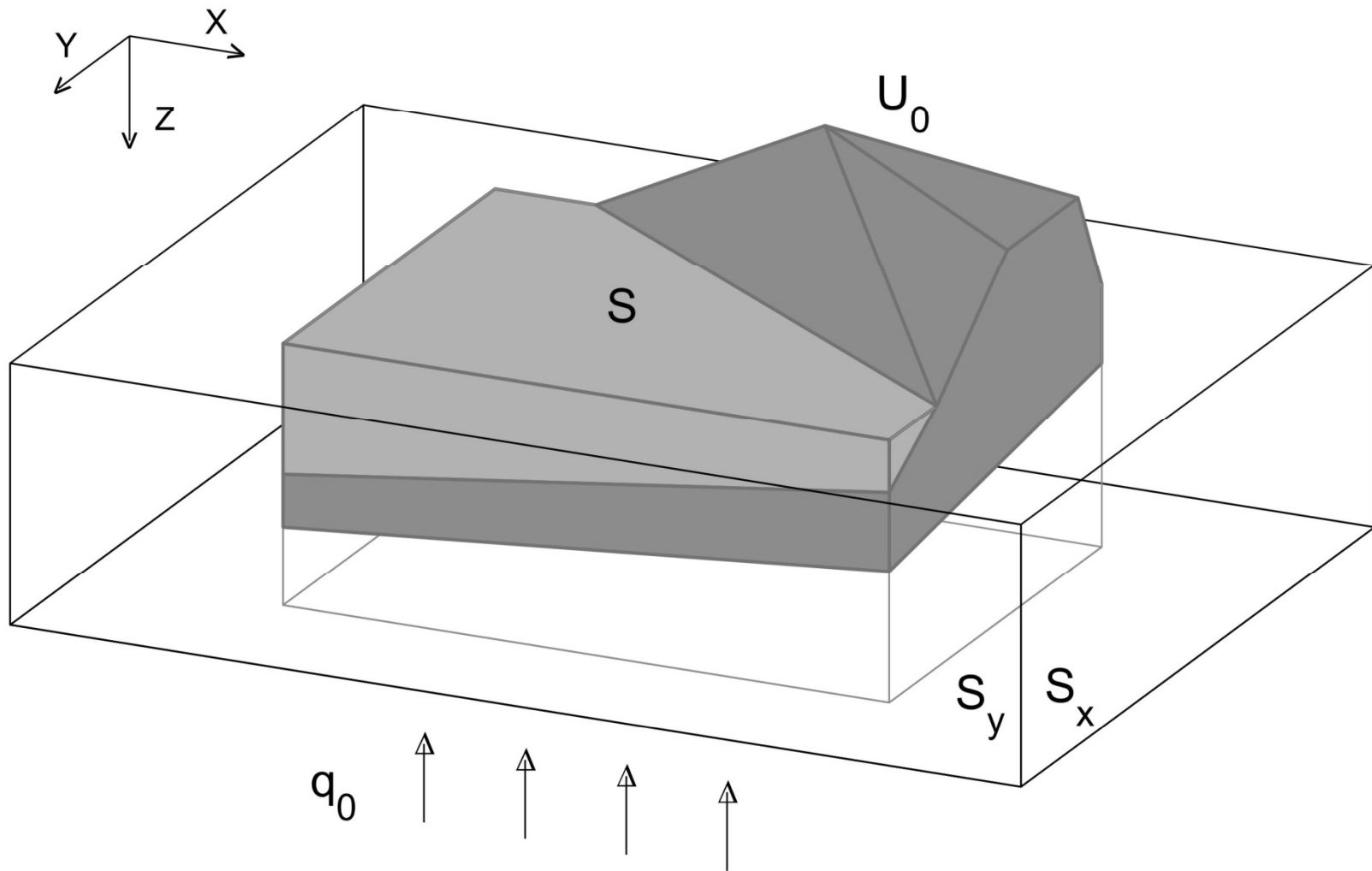
Motivácia, podnety:

Modelovanie teplotných polí v prostredí Západných Karpát

Prechod od dvojrozmerných stacionárnych metód k trojrozmerným a nestacionárnym prístupom; typy zdrojov anomálií – nejednoznačnosť riešení; interpretácia nameraných hodnôt hustoty tepelného toku, konštrukcia a použitie geotermických máp,...

Témy Vega projektov na oddeleniach gravimetrie a geomagnetizmu

„Analýza robustnosti vybraných gravimetrických a geodynamických interpretačných metód v geofyzikálnych obrátených úlohách“



Všeobecná konfigurácia modelov refrakcie tepelného toku

Štruktúry s najväčšími rozdielmi v koeficiente tepelnej vodivosti vo vrchnej kôre a kontrastné štruktúry priamo na povrchu Zeme – okraje sedimentárnych bazénov, hráste, priekopové prepadliny, zlomové pásma, ....

$$\operatorname{div} ( k(x, y, z) \operatorname{grad} U(x, y, z) ) = 0 \quad (1)$$

$$U(x, y, z)|_S = U_0(x, y, z) \quad (2)$$

$$k(x, y, z) \frac{\partial U(x, y, z)}{\partial z} \Big|_{z=h} = q_0 \quad (3)$$

$$k(x, y, z) \frac{\partial U(x, y, z)}{\partial x} \Big|_{S_x} = 0 \quad (4)$$

$$k(x, y, z) \frac{\partial U(x, y, z)}{\partial y} \Big|_{S_y} = 0$$

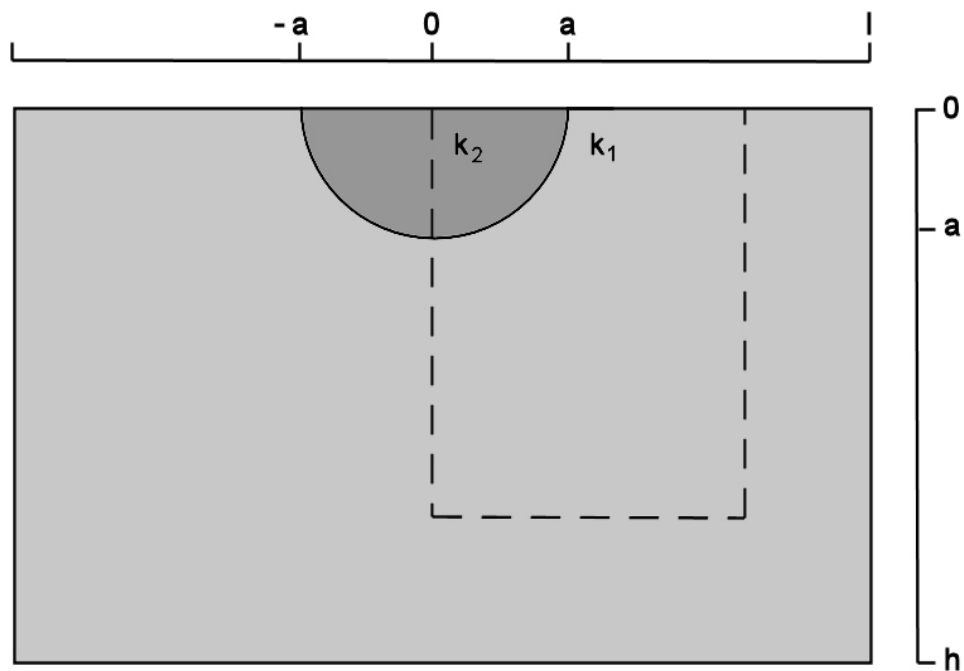
$$\lim_{X_1 \rightarrow X_0} U(X_1) = \lim_{X_2 \rightarrow X_0} U(X_2),$$

$$\lim_{X_1 \rightarrow X_0} \left\{ k(X_1) \frac{\partial U(X_1)}{\partial n} \right\} = \lim_{X_2 \rightarrow X_0} \left\{ k(X_2) \frac{\partial U(X_2)}{\partial n} \right\}, \quad (5)$$

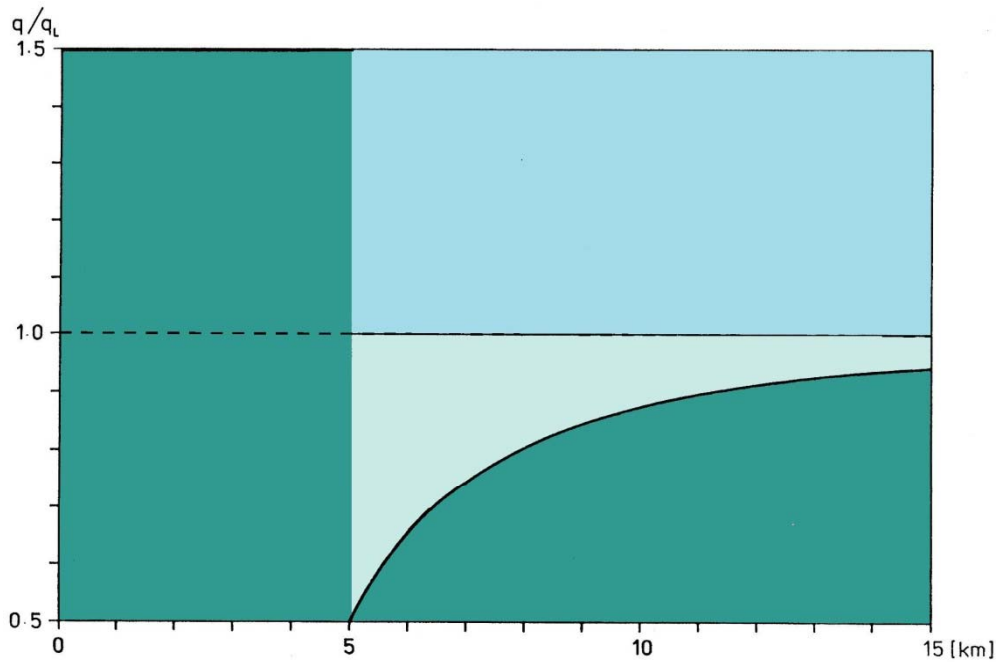
$$X_1 \in M_1, X_2 \in M_2, X_0 \in S_{1,2}.$$

Riešenia refrakčných úloh (1 – 5) v uzavretom analytickom tvare, metódou konečných diferencií a metódou hraničných integrálnych rovníc.

Konfigurácia modelu refrakcie tepelného toku na polvalcovej vodivostnej nehomogenite uloženej k povrchu polpriestoru.



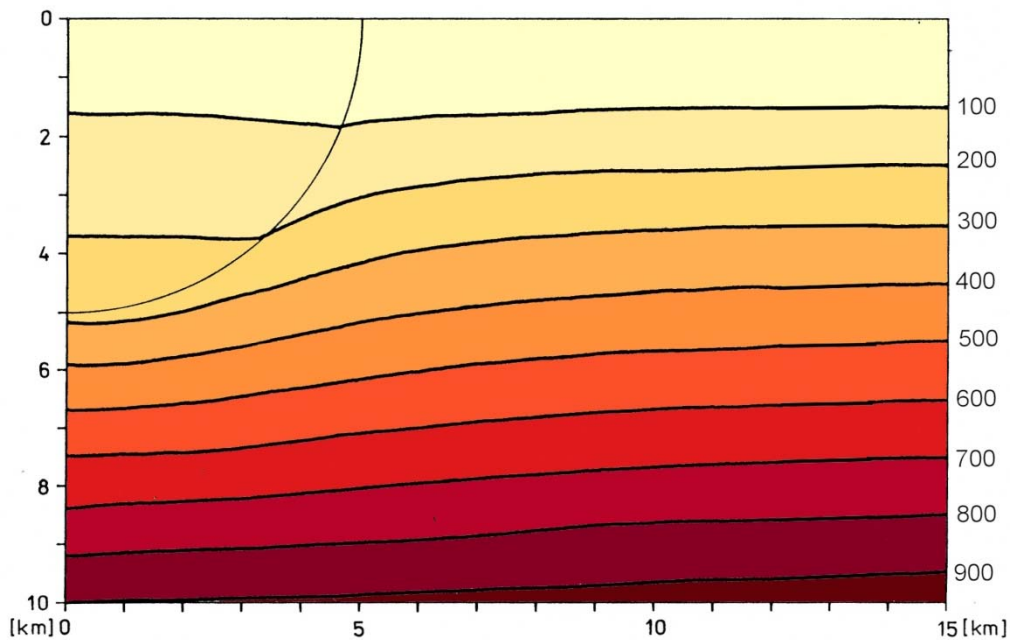
$$q(x) = \begin{cases} q_0 \left( 1 + \frac{1 - k_2/k_1 a^2}{1 + k_2/k_1 x^2} \right), & |x| > a, \\ q_0 \left( 2 \frac{k_2/k_1}{1 + k_2/k_1} \right), & |x| < a, \end{cases}$$



Relatívne hodnoty hustoty povrchového tepelného toku

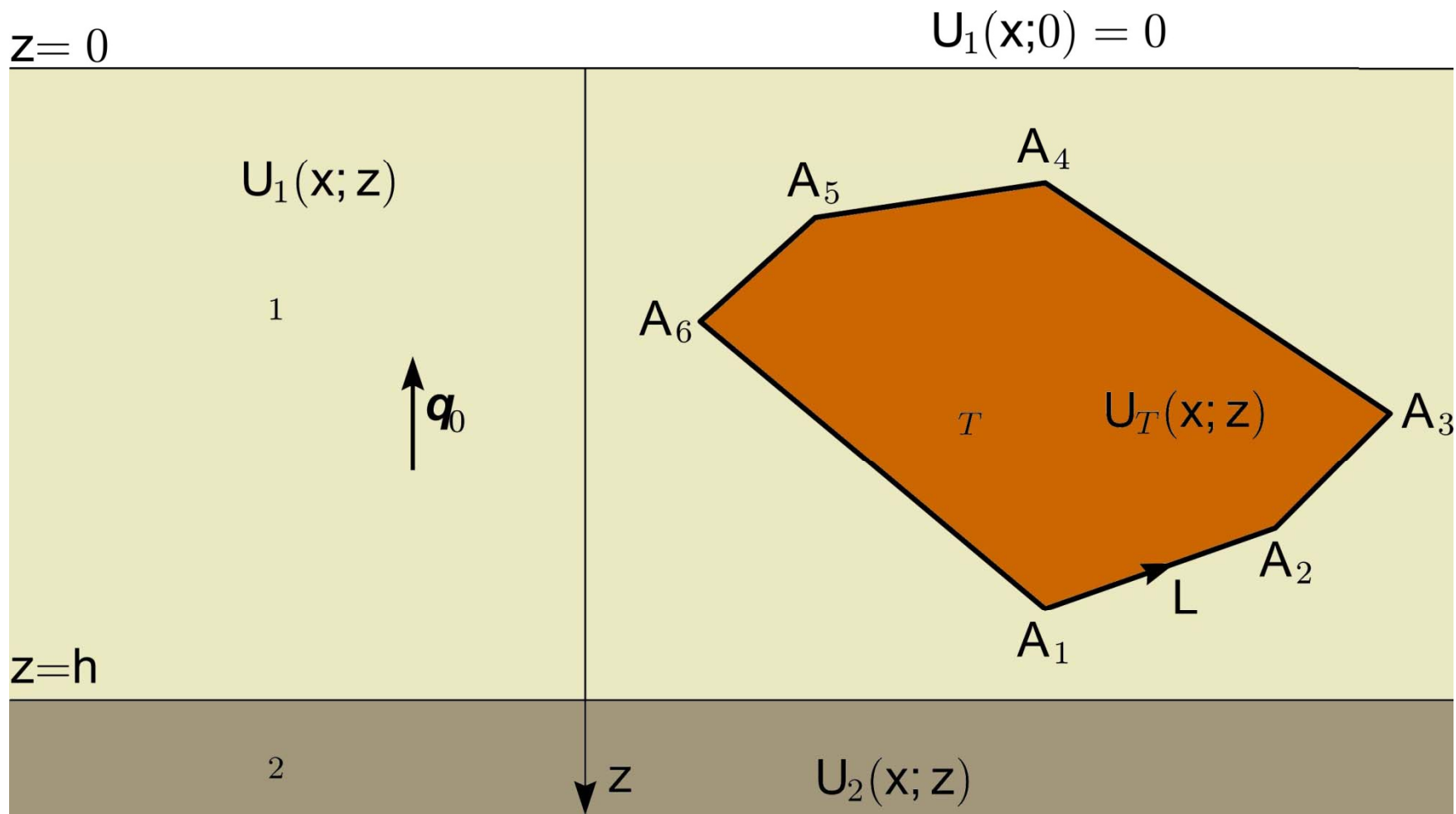
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$$\frac{\kappa_2}{\kappa_1} = 3.00$$



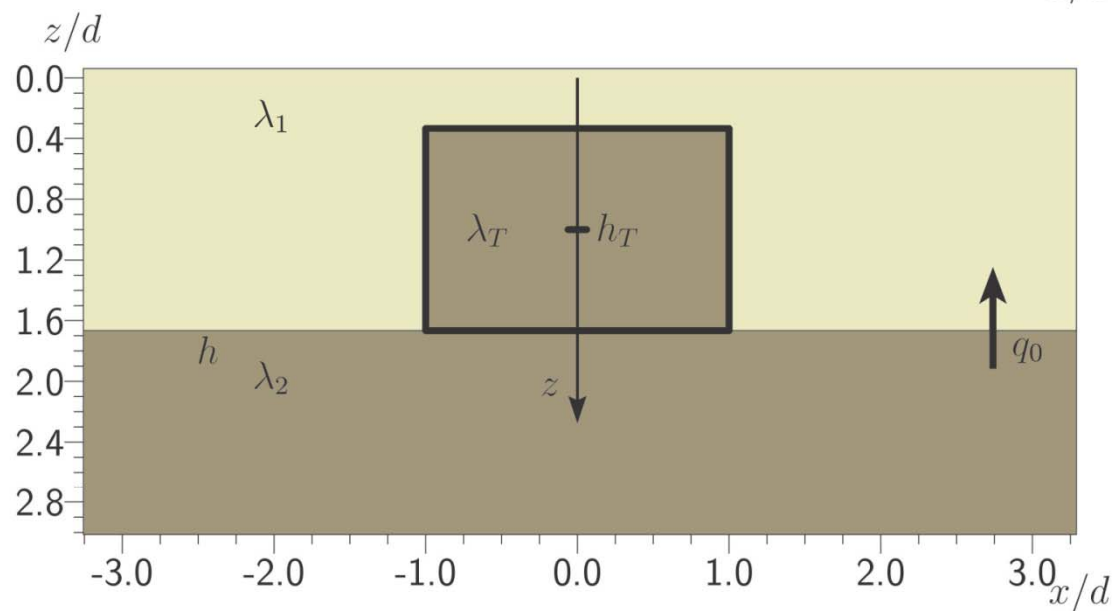
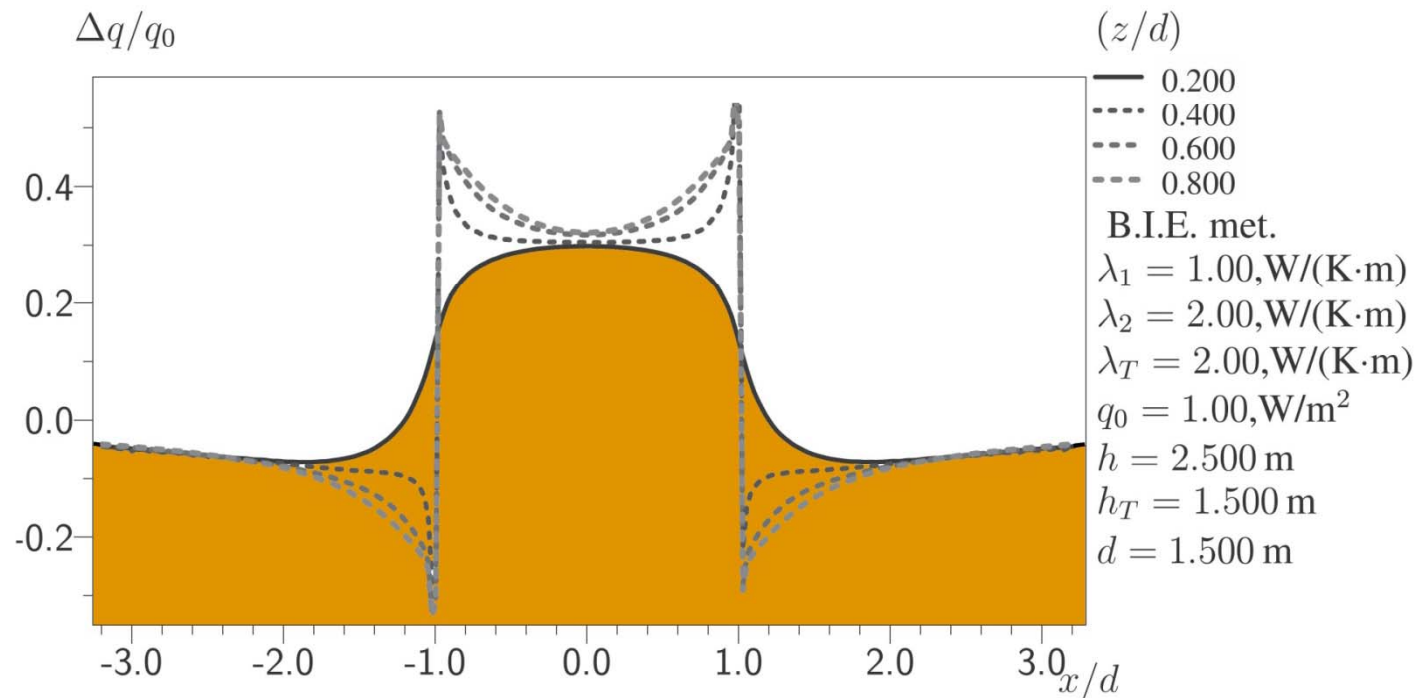
Rozloženie teploty

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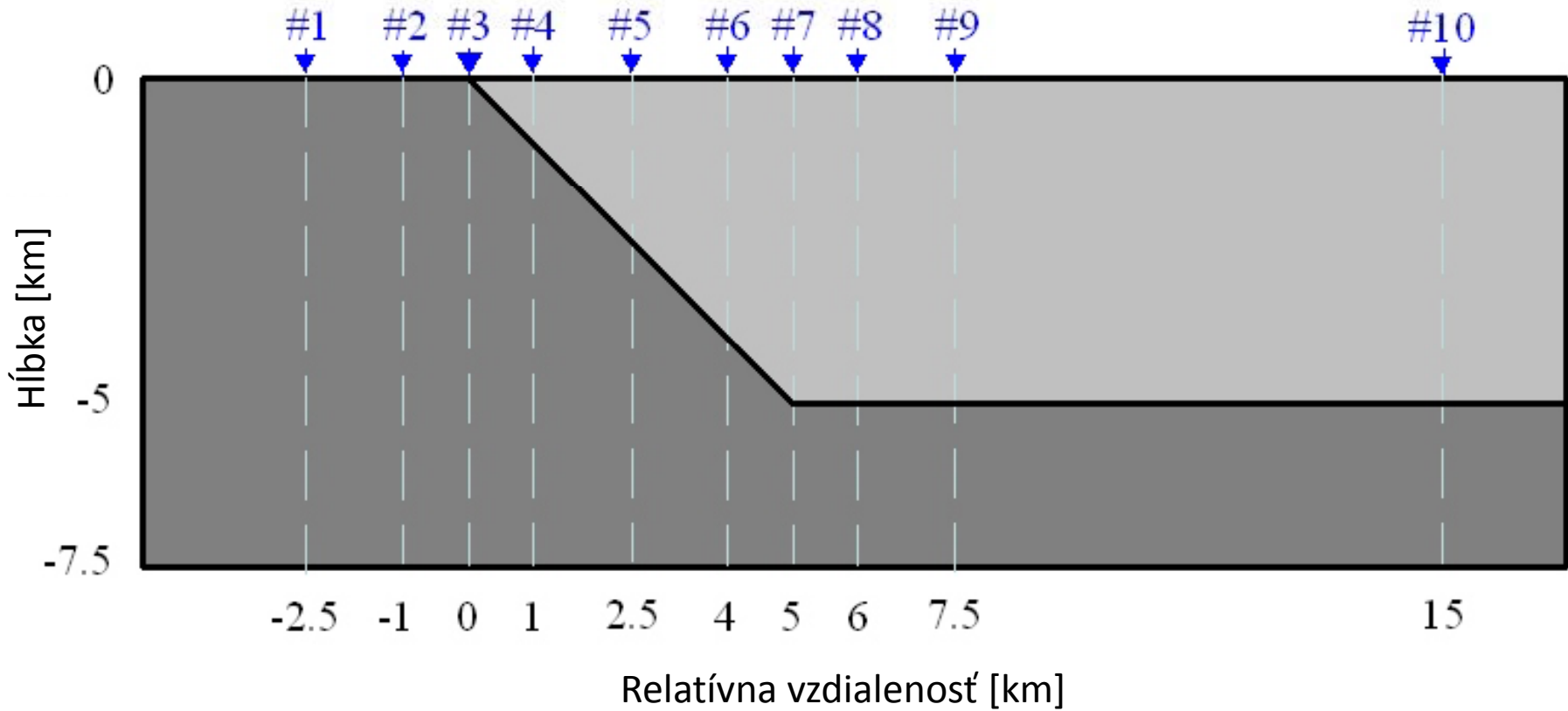


Konfigurácia modelu dvojvrstvovej Zeme s polygonálnou vodivostnou nehomogenitou

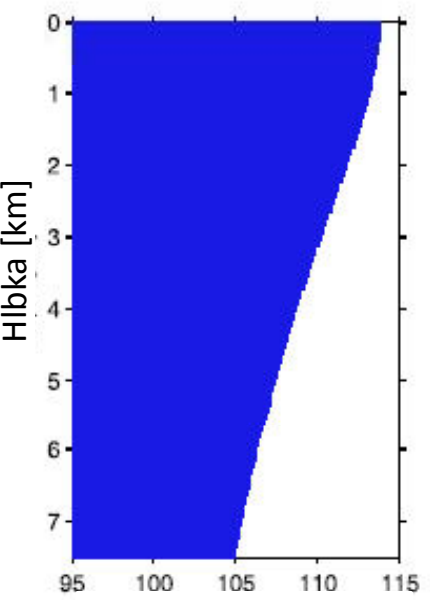
# Hrást



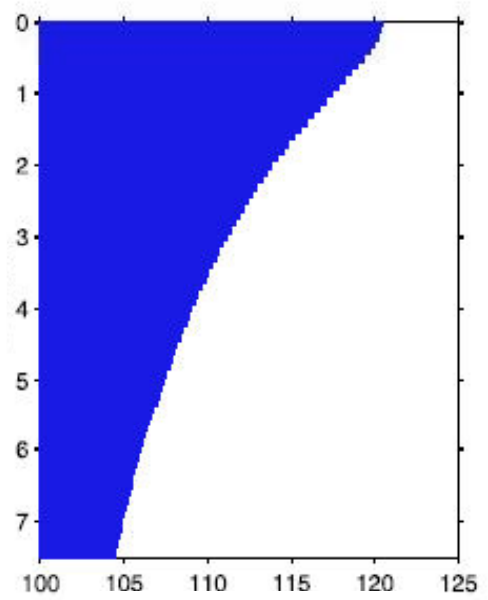




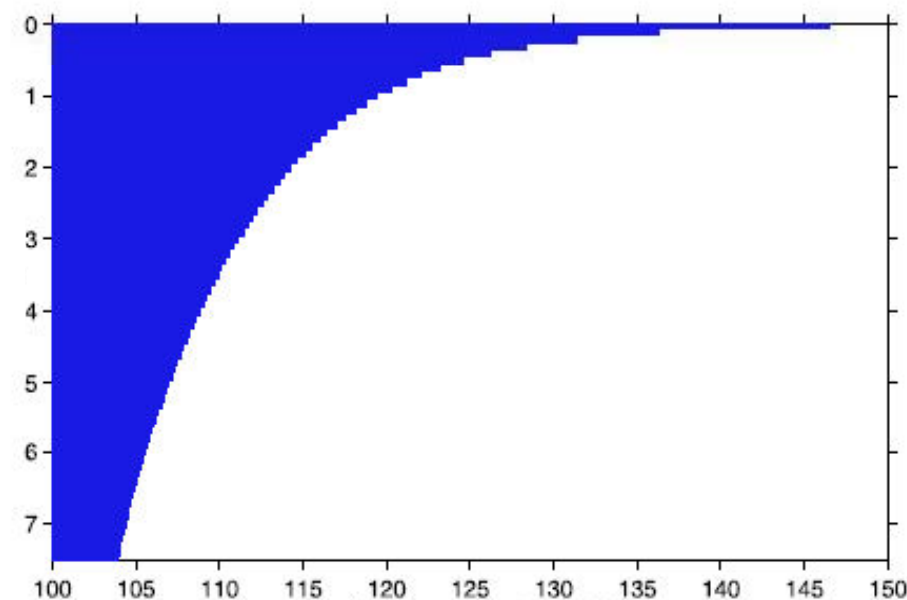
#1



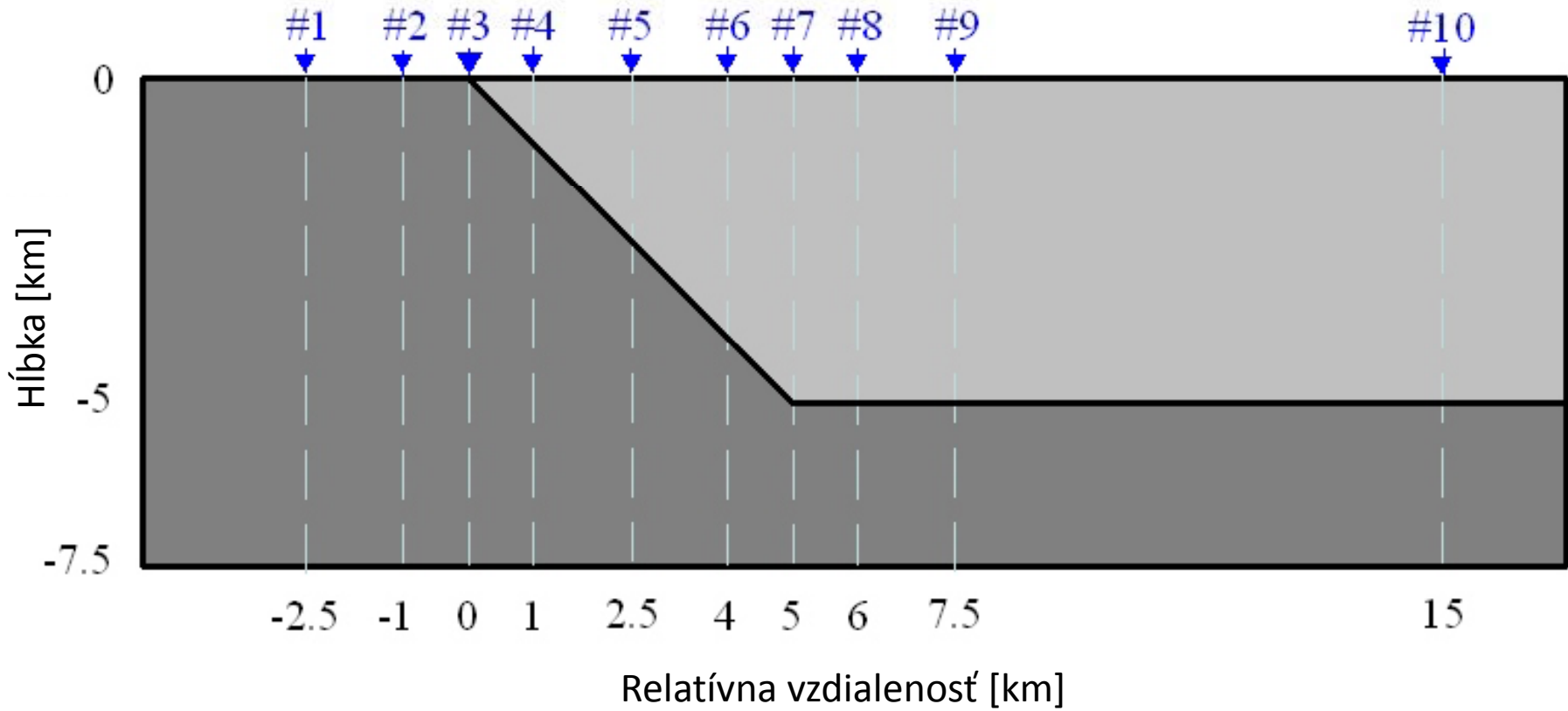
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#3



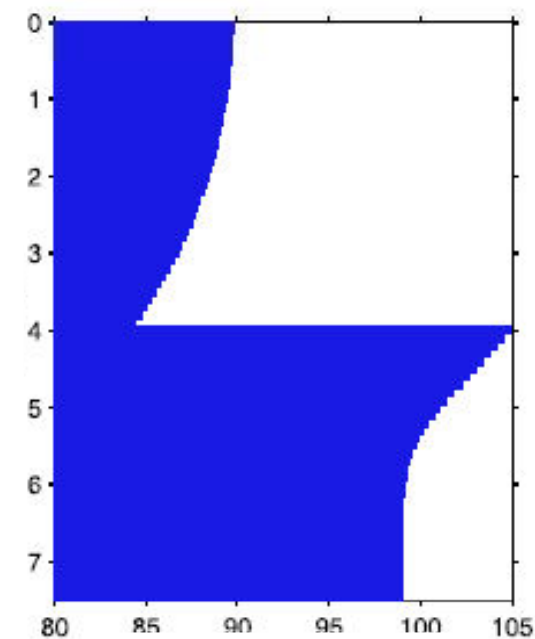
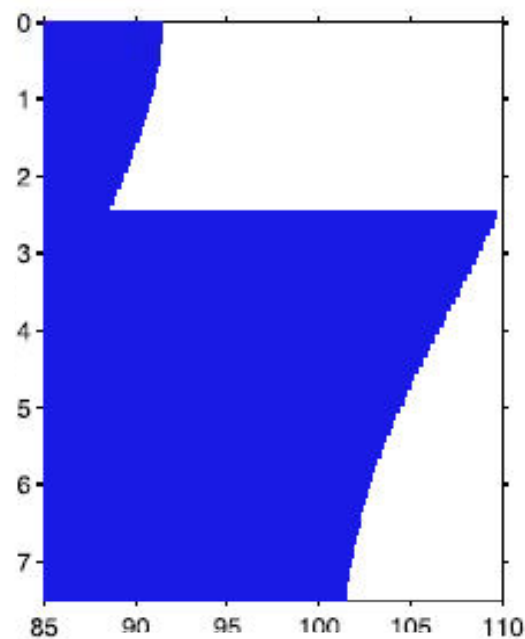
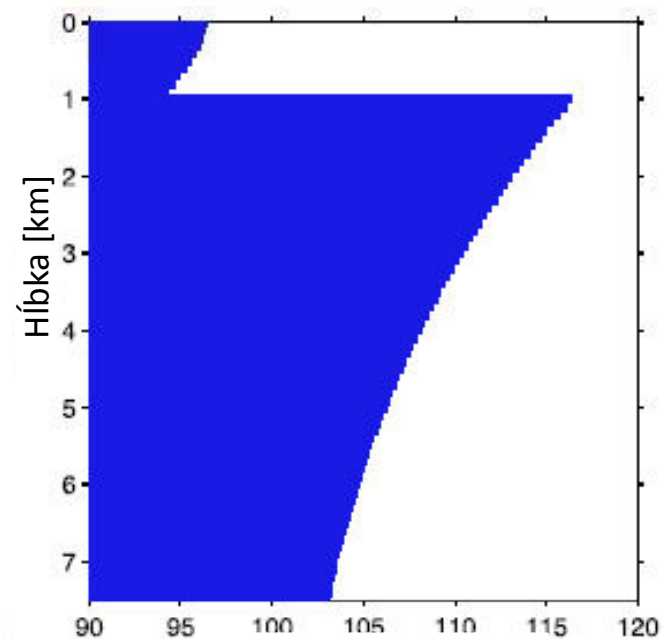
relatívna hustota tepelného toku [%]



# #4

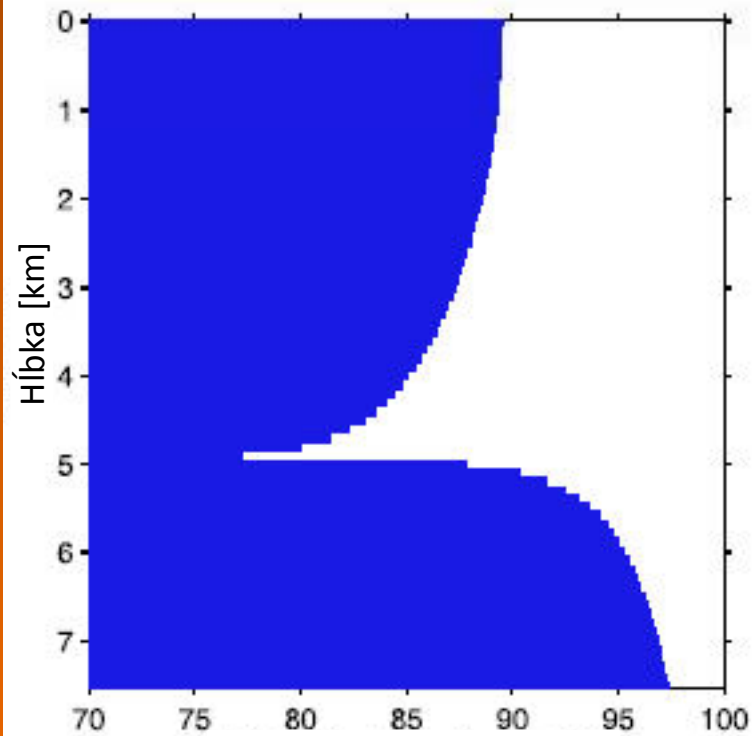
# #5

# #6

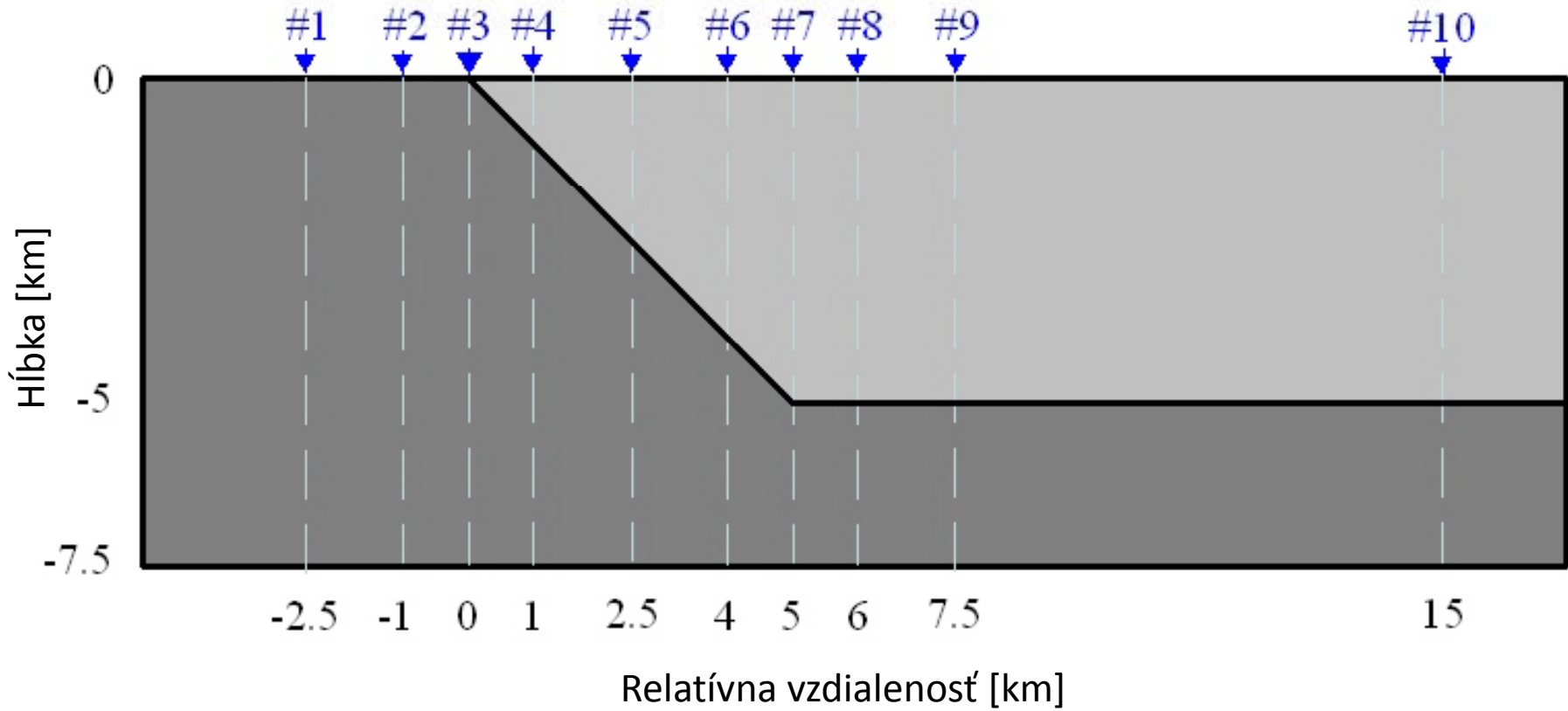


relatívna hustota tepelného toku [%]

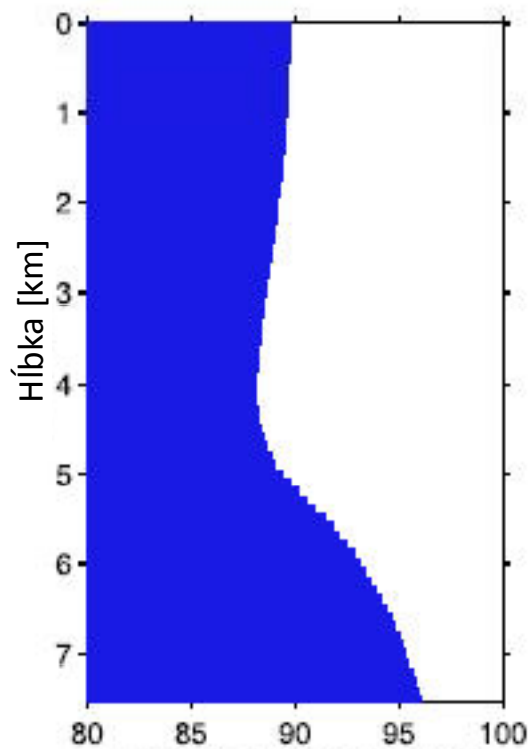
#7



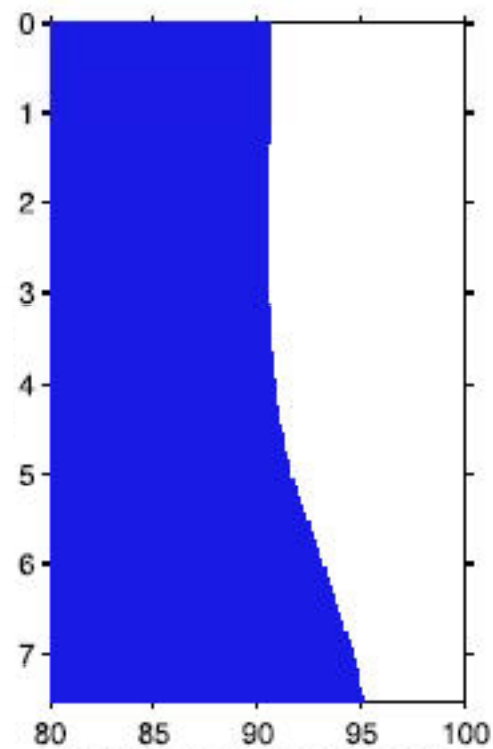
relatívna hustota tepelného toku [%]



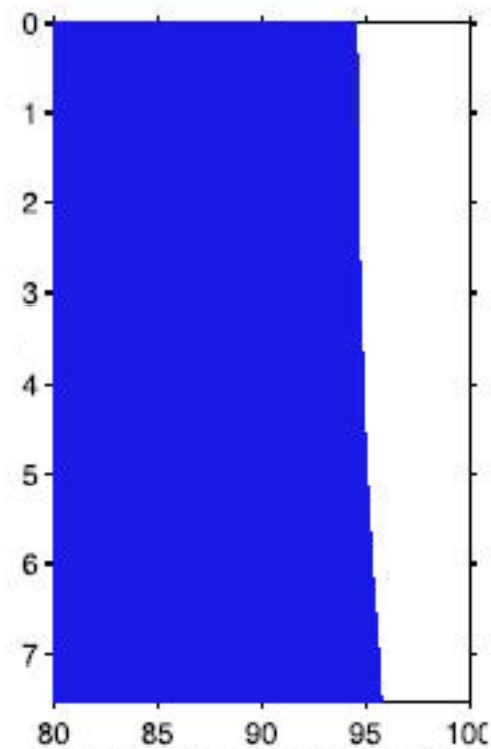
# #8



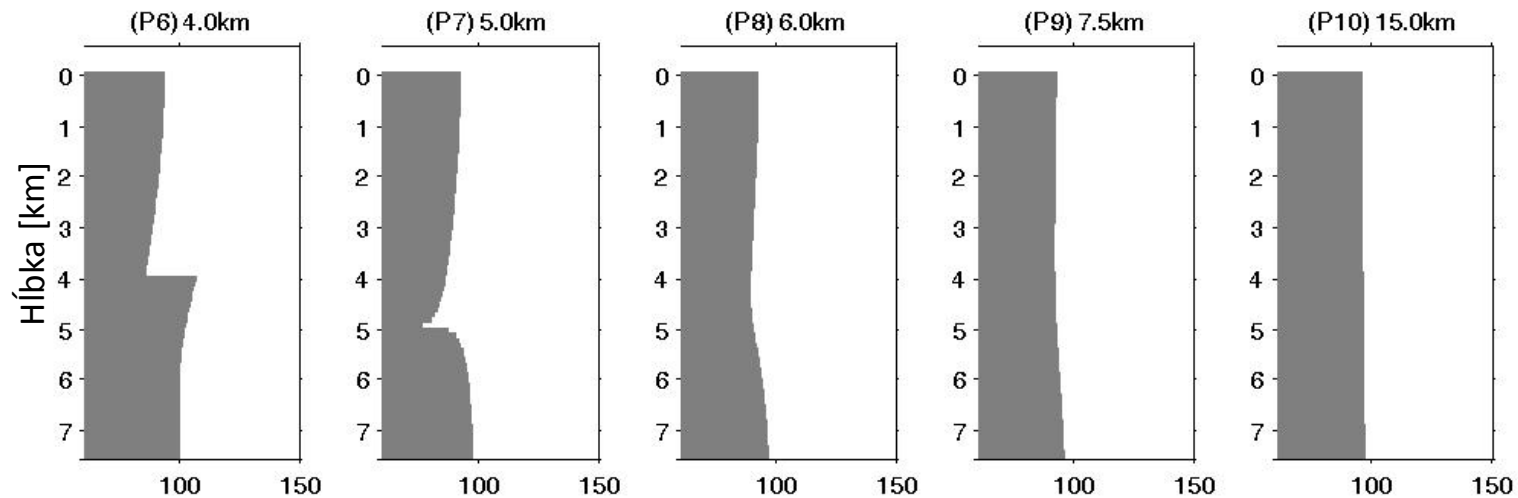
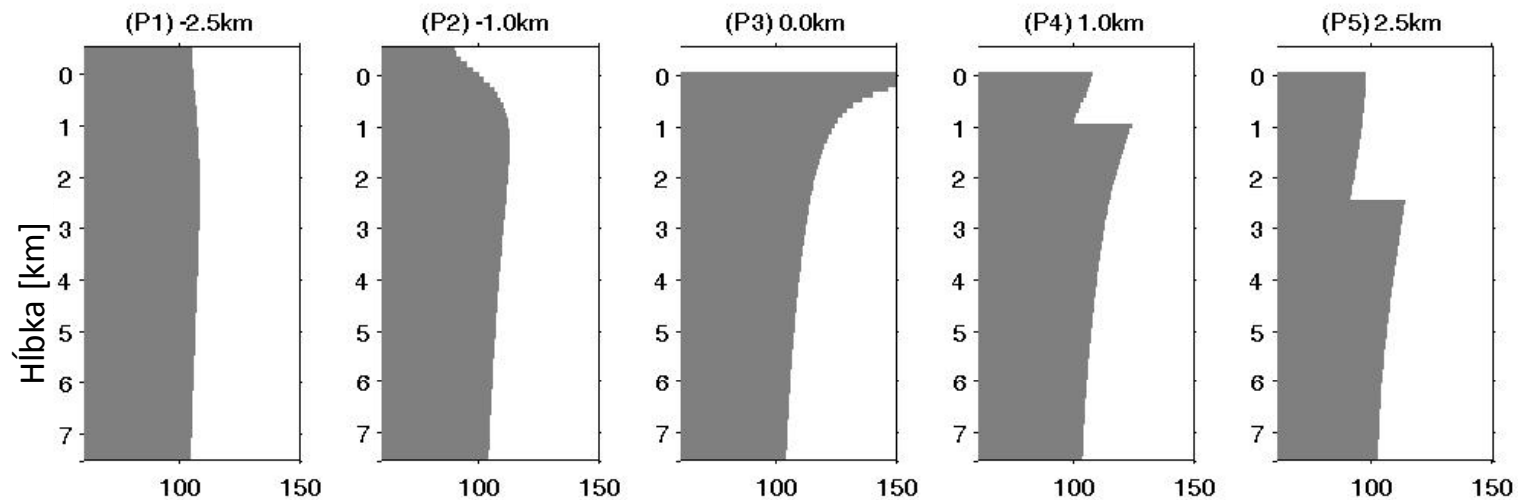
# #9



# #10

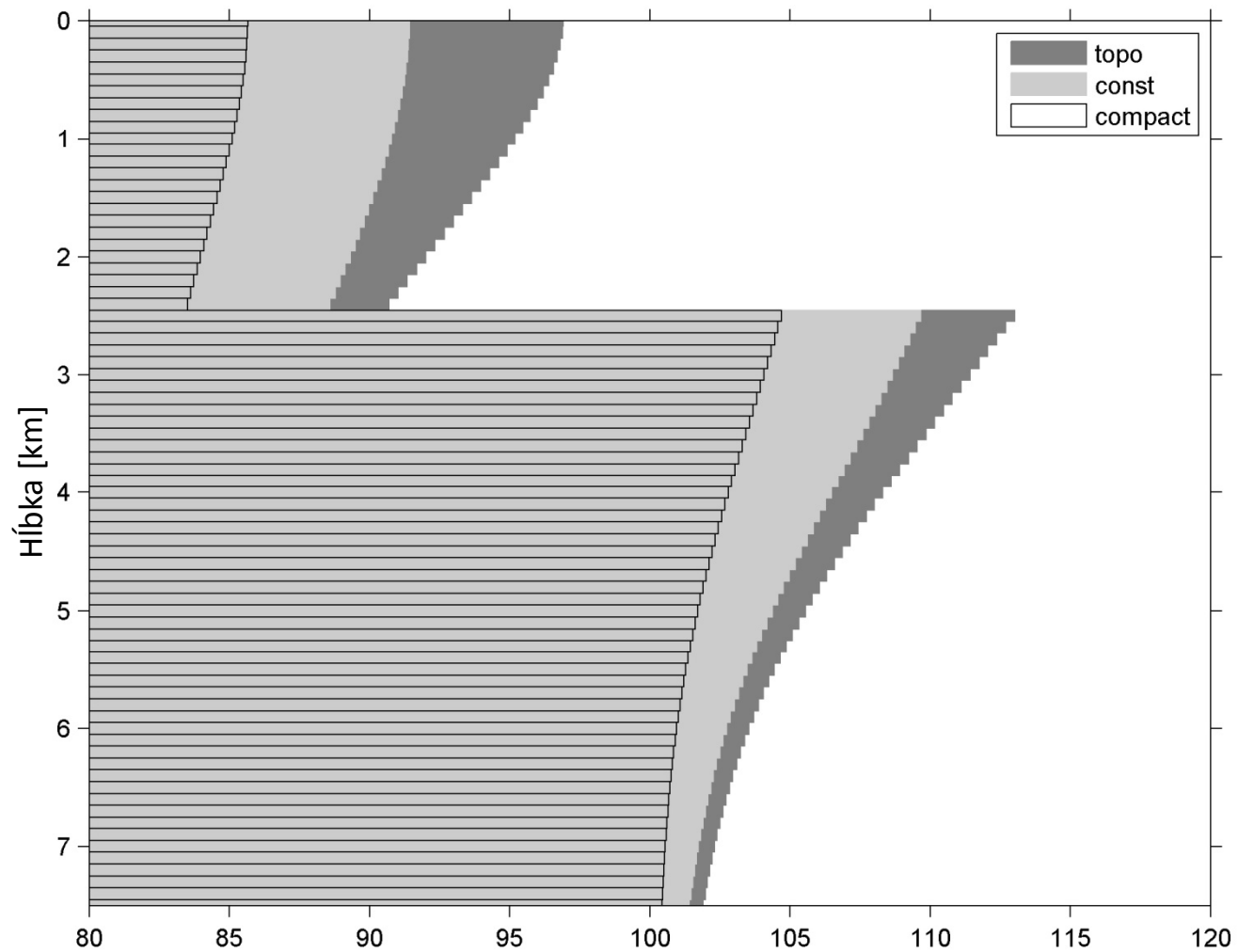


relativná hustota tepelného toku [%]



relatívna hustota tepelného toku [%]

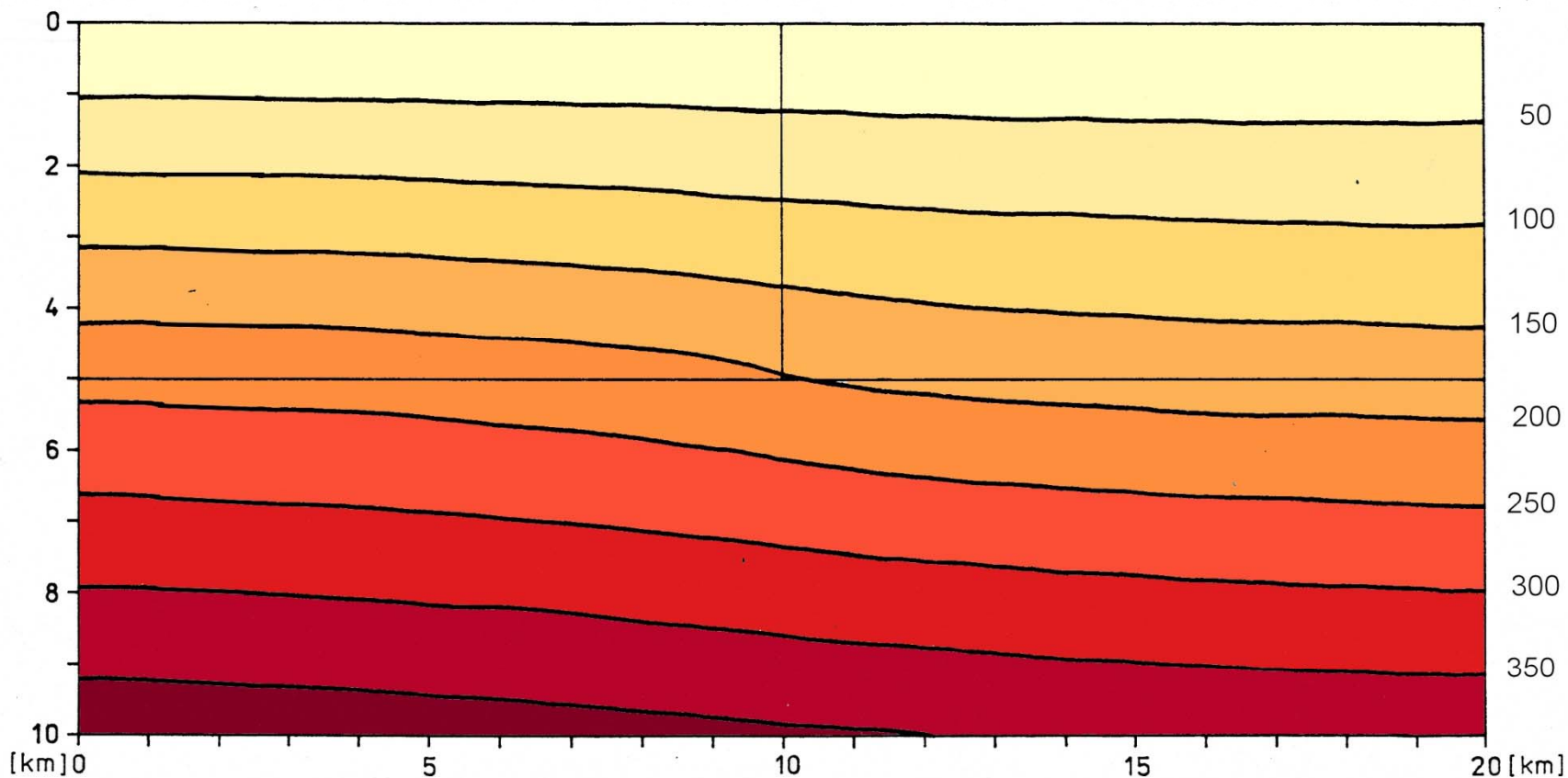
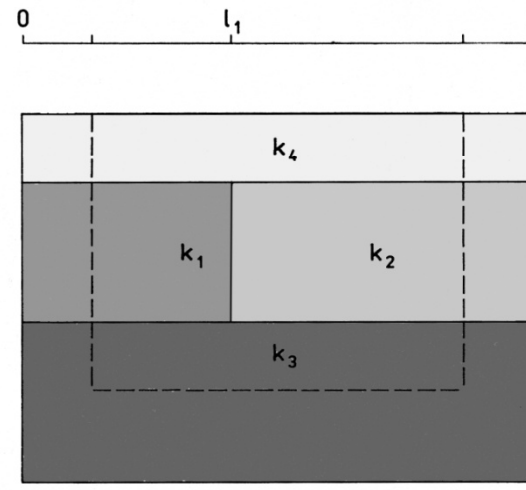




relatívna hustota tepelného toku [%]; porovnanie v bode #5

Rozloženie teploty z refrakcie tepelného toku na  
kontrastnej štruktúre s vertikálnou hranicou blokov.  
(  $h_1 = 0$ ,  $h_2 = 5000$  m, teplotné izolínie v  $^{\circ}\text{C}$  )

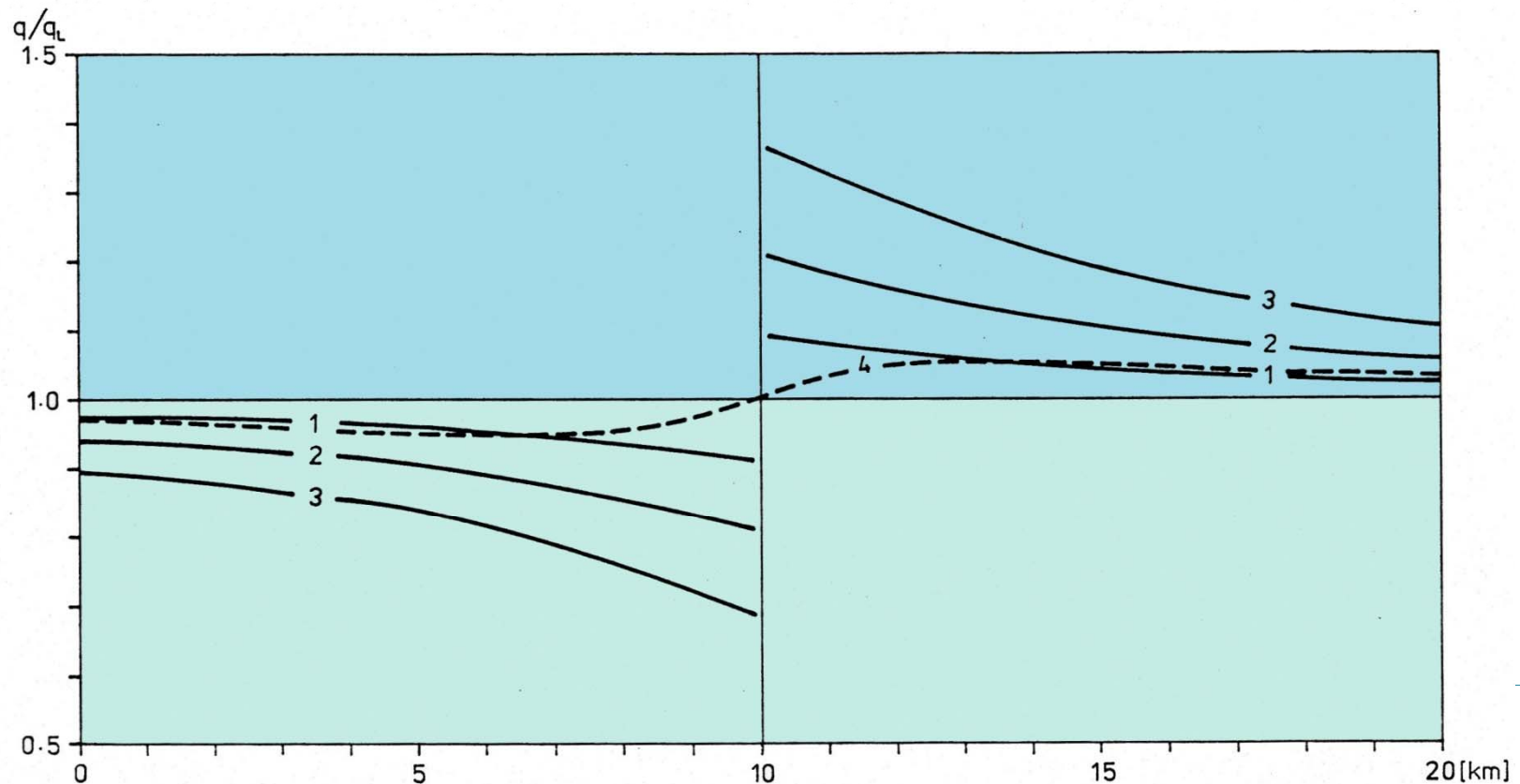
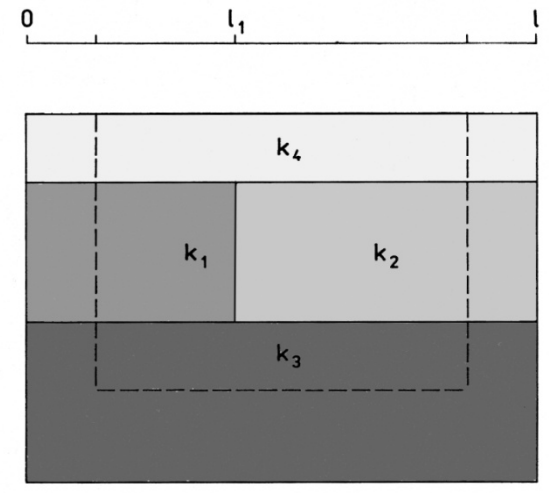
$$k_2 / k_1 = 3.00/2.00$$

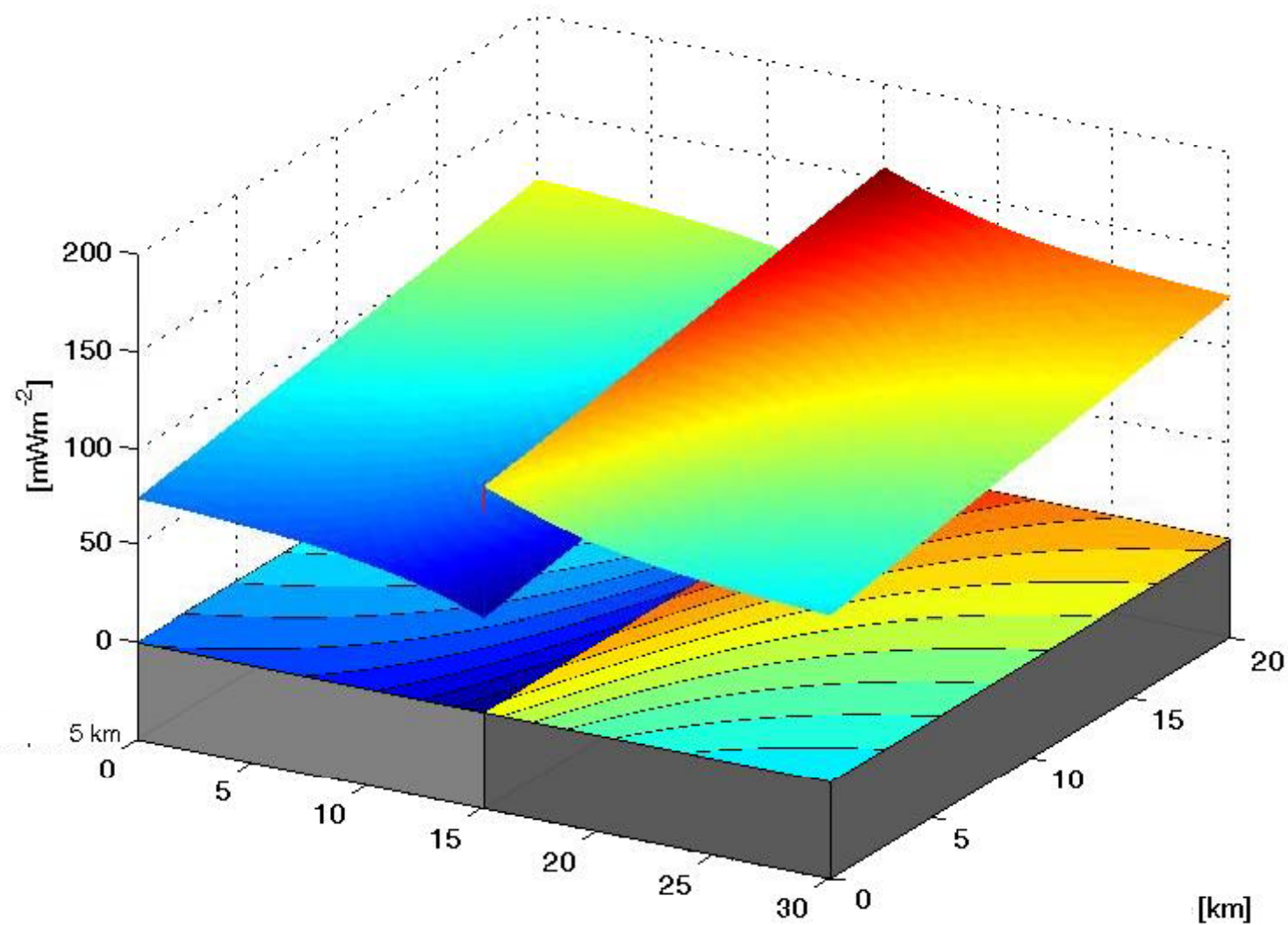


Relativne hodnoty hustoty povrchového tepelného toku pre modely bez vrstvy pokryvu ( $h_1 = 0$ , plné čiary) a s ním ( $h_1 = 2000$ , čiarkovane);  $h_2 = 5000$ .

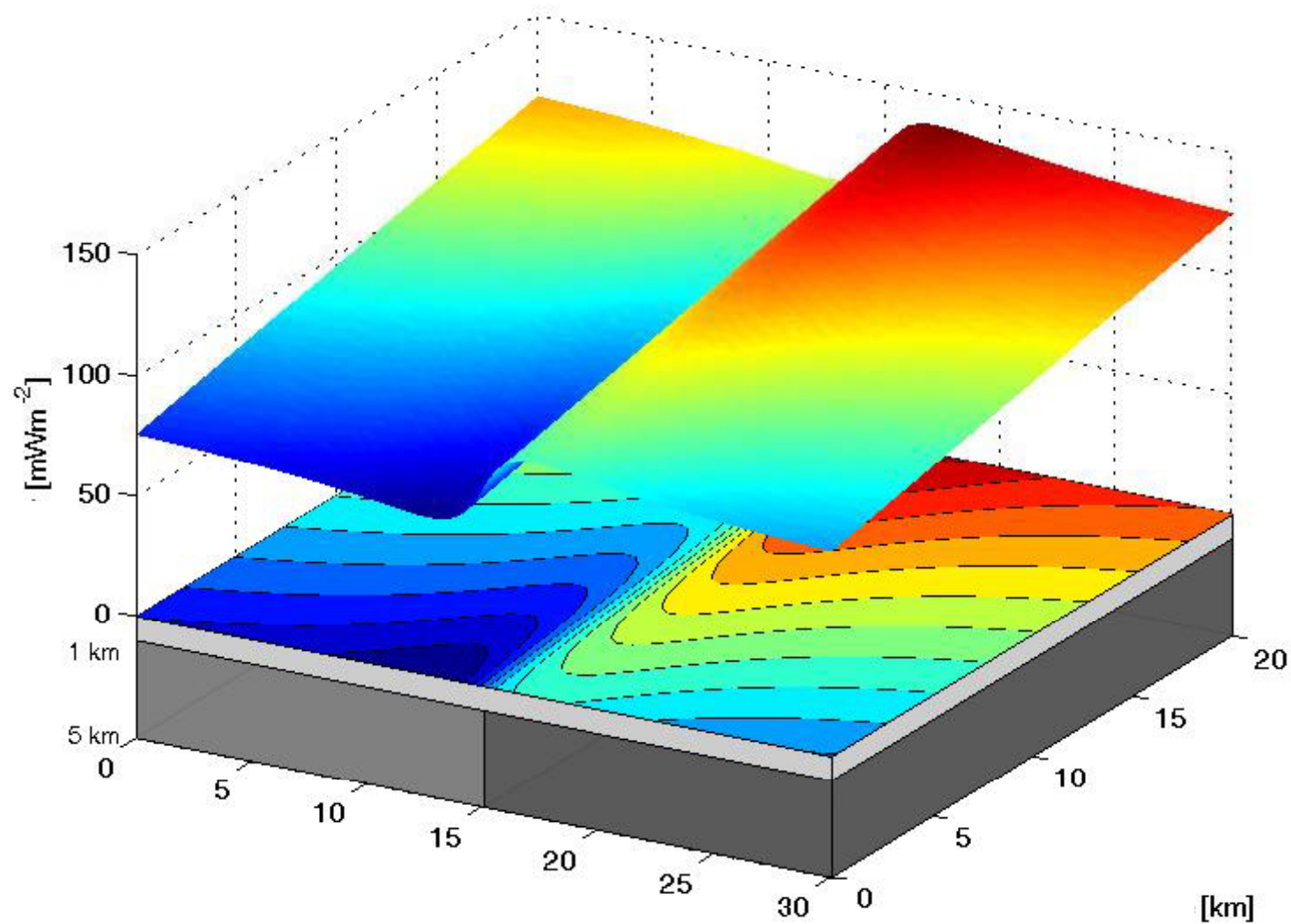
Vodivostný kontrast  $k_2 / k_1$  je :

|     |           |
|-----|-----------|
| 1   | 3.00/2.50 |
| 2,4 | 3.00/2.00 |
| 3   | 3.00/1.50 |



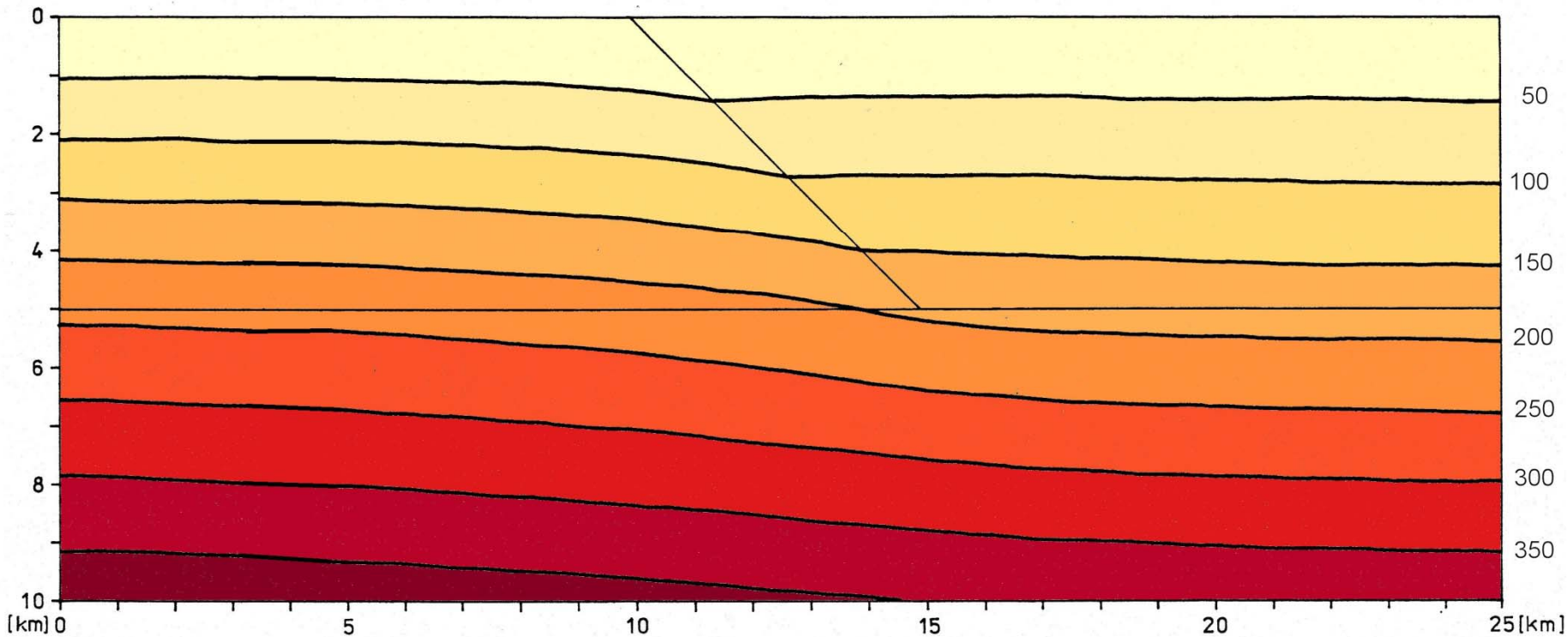
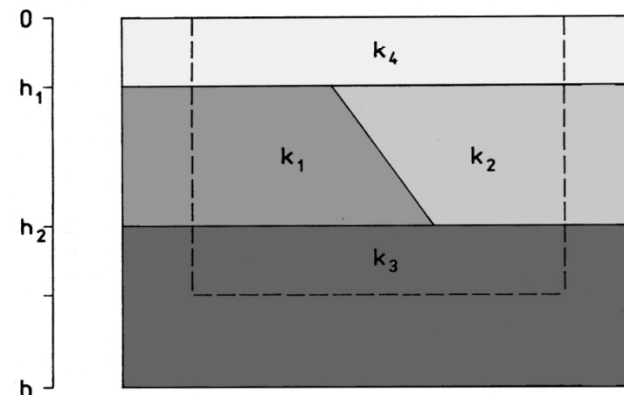
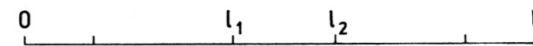


Hustota refragovaného povrchného tepelného toku s gradientom pozdĺž hranice



Hustota refragovaného povrchového tepelného toku s gradientom pozdĺž hranice a pokryvom

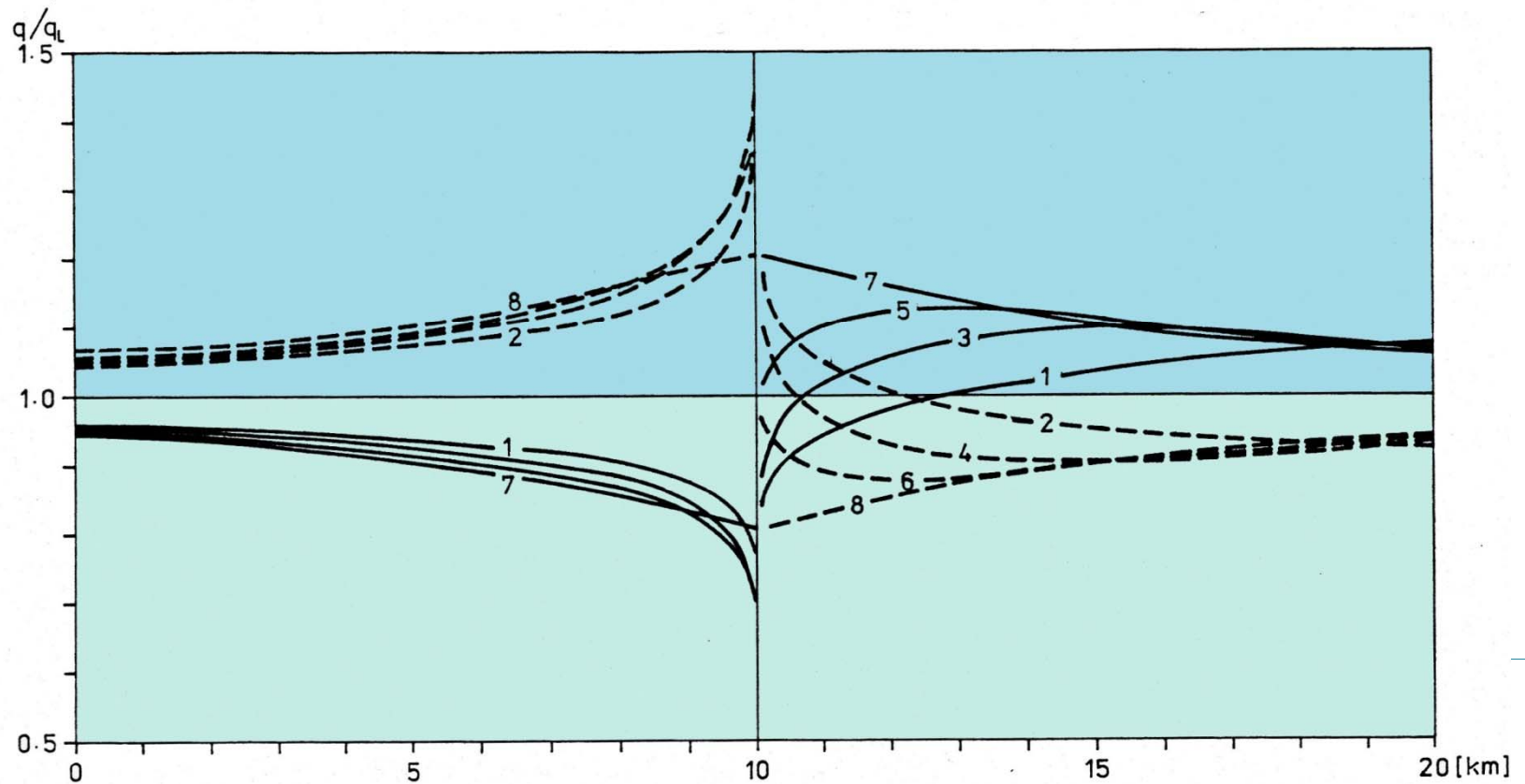
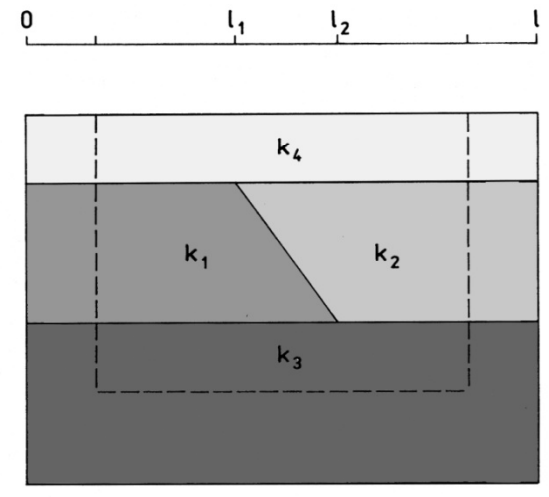
Teplotné pole ovplyvnené refrakciou tepelného toku  
 na kontrastnej štruktúre so šikmou kontaktnou hranicou.  
 (  $h_1 = 0$ ,  $h_2 = 5000$  m, izolínie teploty v  $^{\circ}\text{C}$  )  
 $k_2 / k_1 = 3.00/2.00$ , uhol 45 stupňov

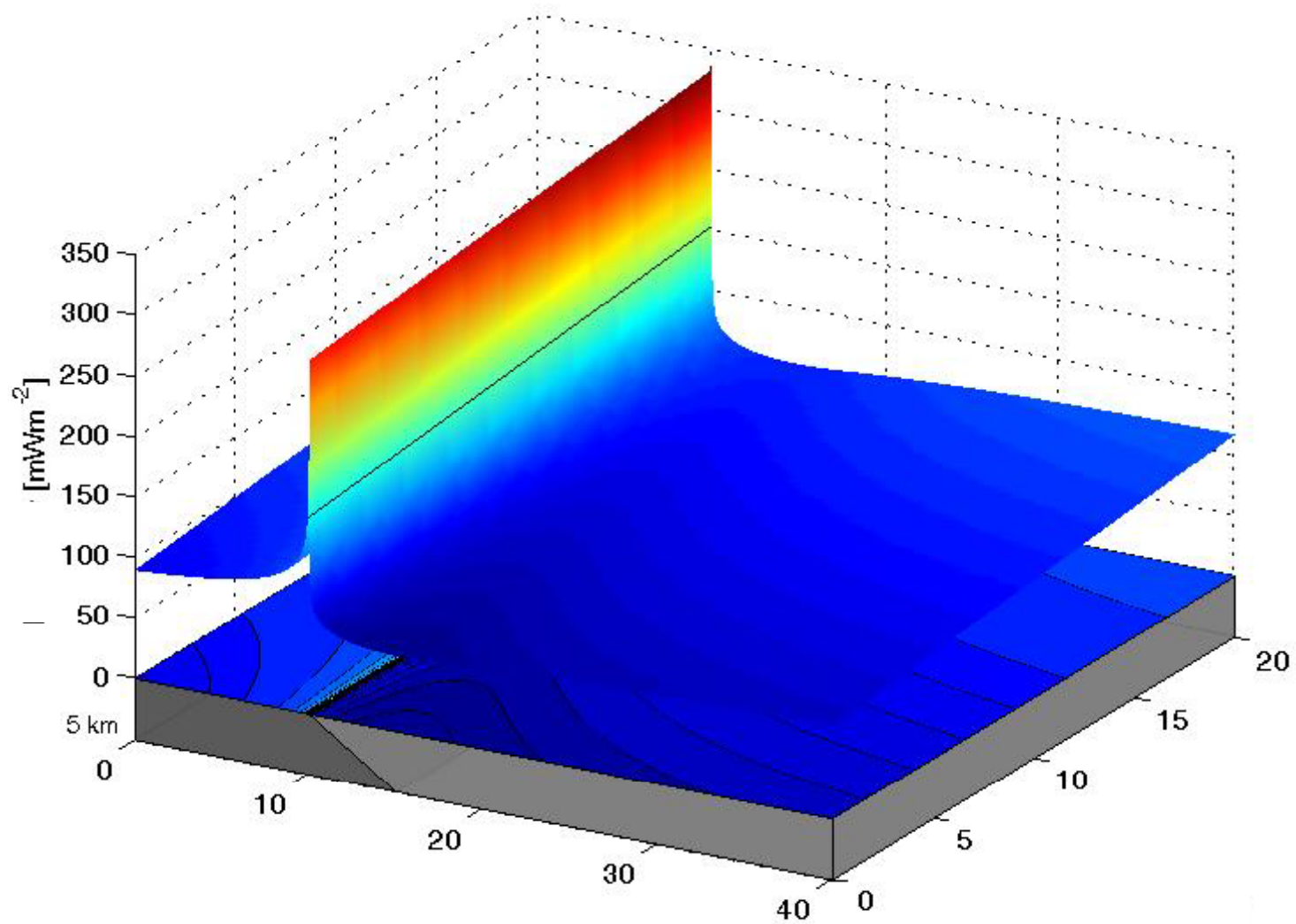


Relatívne hodnoty hustoty povrchového tepelného toku pre modely bez pokrývajúcej vrstvy ( $h_1 = 0$ ); s fixovanou hodnotou  $h_2 = 5000$  m; kontrast tepelnej vodivosti je  $k_2 / k_1 = 3.00/2.00$  plnou čiarou a  $k_2 / k_1 = 2.00/3.00$  čiarkovane. Uhol kontaktnej hranice sa menil

$$l_2 - l_1 = b * h_2.$$

|     |          |     |           |
|-----|----------|-----|-----------|
| 1,2 | $b = 2;$ | 5,6 | $b = 0.5$ |
| 3,4 | $b = 1;$ | 7,8 | $b = 0.0$ |



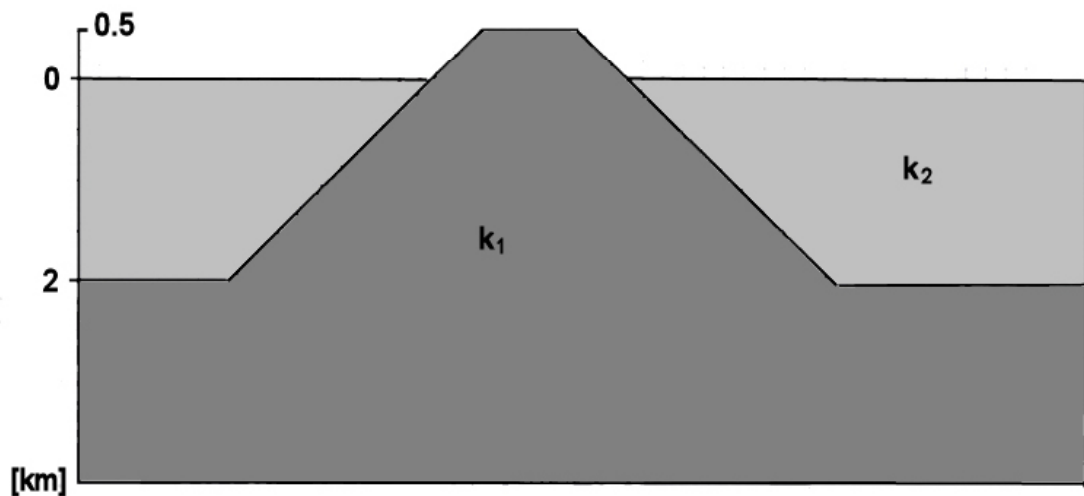
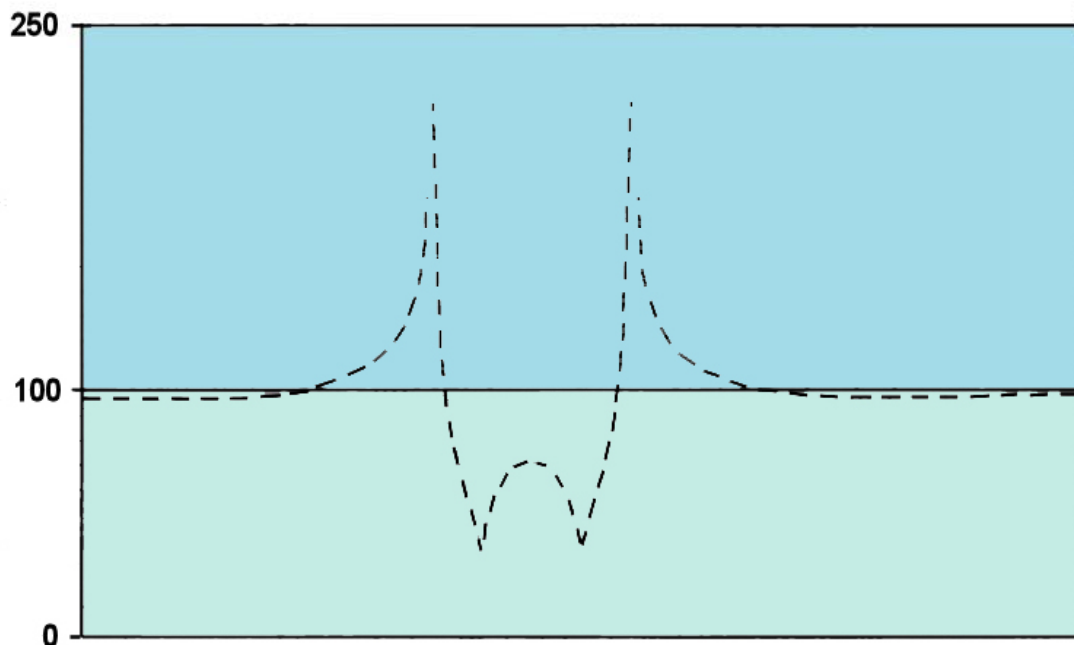


Hustota refragovaného povrchového tepelného toku s gradientom pozdĺž hranice



Relatívne hodnoty hustoty  
povrchového tepelného  
toku v percentách  
refragovaného toku  
pre model horského  
chrbtu obklopeného  
sedimentárnymi bazénmi  
(kotlinami). Vodivostný  
kontrast je:

$$k_2 / k_1 = 2.00/3.00$$



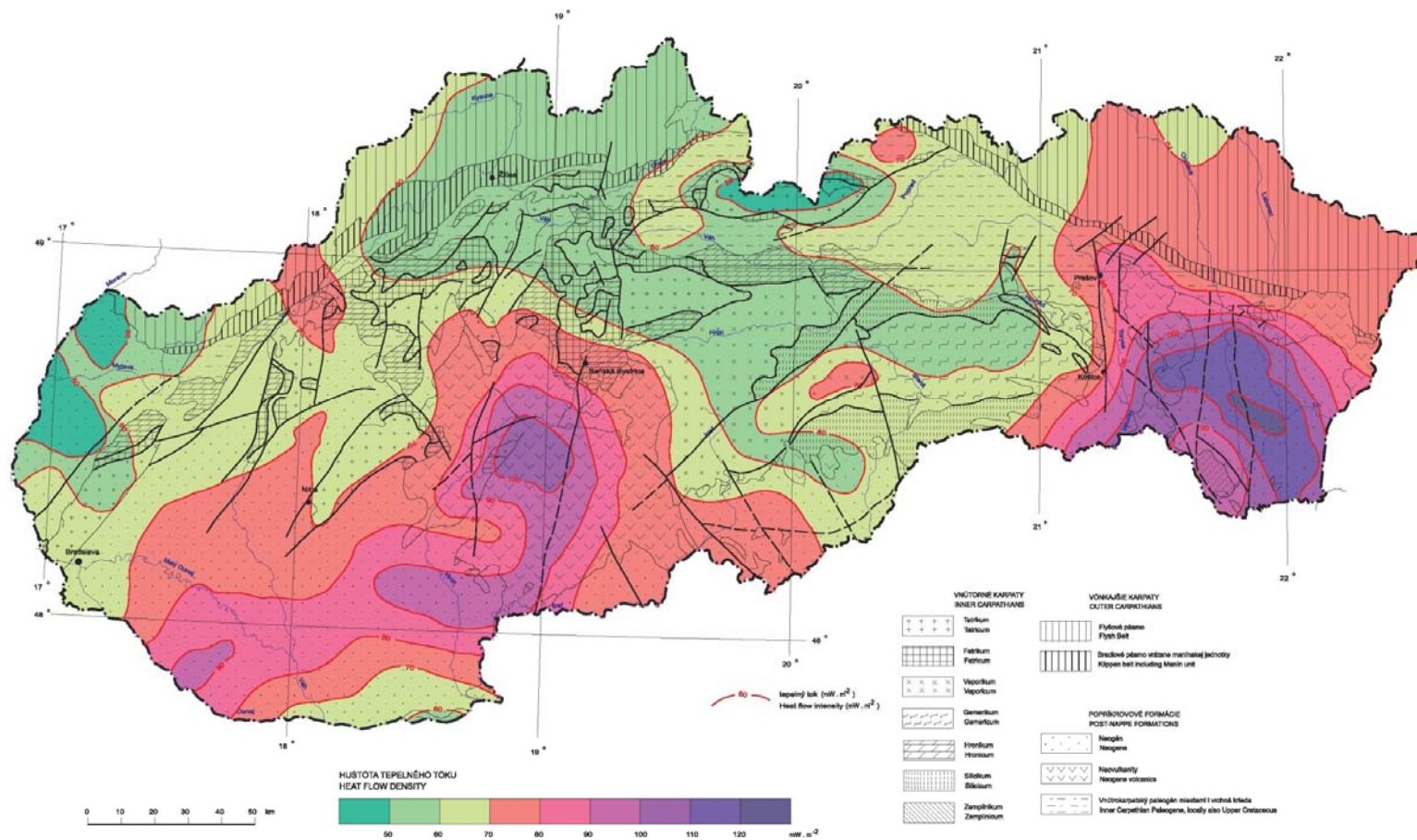
# Určenie hodnôt hustoty povrchového tepelného toku

Získané sady modelov a doplnkové výpočty refrakčných úloh umožňujú prepočty určených hodnôt vo väčších hĺbkach a tiež určenie regionálneho pozadia odstránením pripovrchových refrakčných efektov.

## Konštrukcia máp rozloženia teplôt a hustoty tepelného toku

Mapy rozloženia teplôt na horizontálnych rezoch zväčša nejavia dramatické zmeny spôsobené refrakciou....

Mapy, hustôt povrchového tepelného toku zväčša nezahŕňajú refrakčné efekty na kontrastných pripovrchových štruktúrach.



Pre konštrukciu lokálnych máp je možné ako doplnkový zdroj informácií využiť sady modelov refrakcie tepelného toku a pre zobrazovanie skokových zmien v hodnotách napríklad aj na ploškach ohraničených rôznymi sieťami definovanými na povrchu Zeme. (geografické siete rôznej veľkosti, trojuholníkové siete,.....)

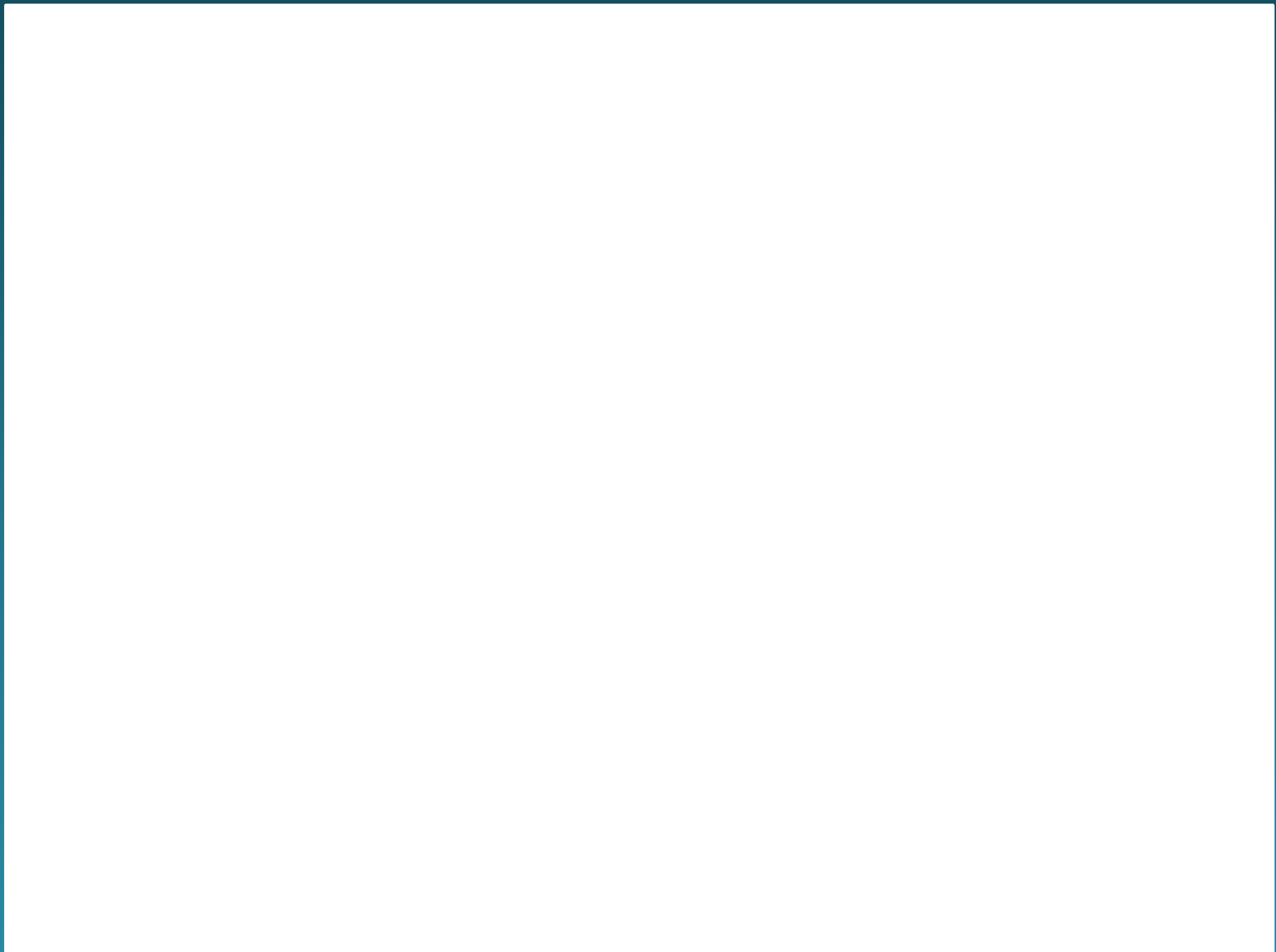
## Modelovanie teplotných polí v oblasti Západných Karpát

Základným zdrojom kontroly modelov teplotných polí sú hustoty povrchových tepelných tokov jednak v podobe máp a po druhé v podobe jednotlivých hodnôt – v oboch prípadoch je potrebná analýza dát.

Sady modelov možno využiť pri primárnej interpretácii vstupných údajov a tiež pri interpretovaní zvyškových anomálií.

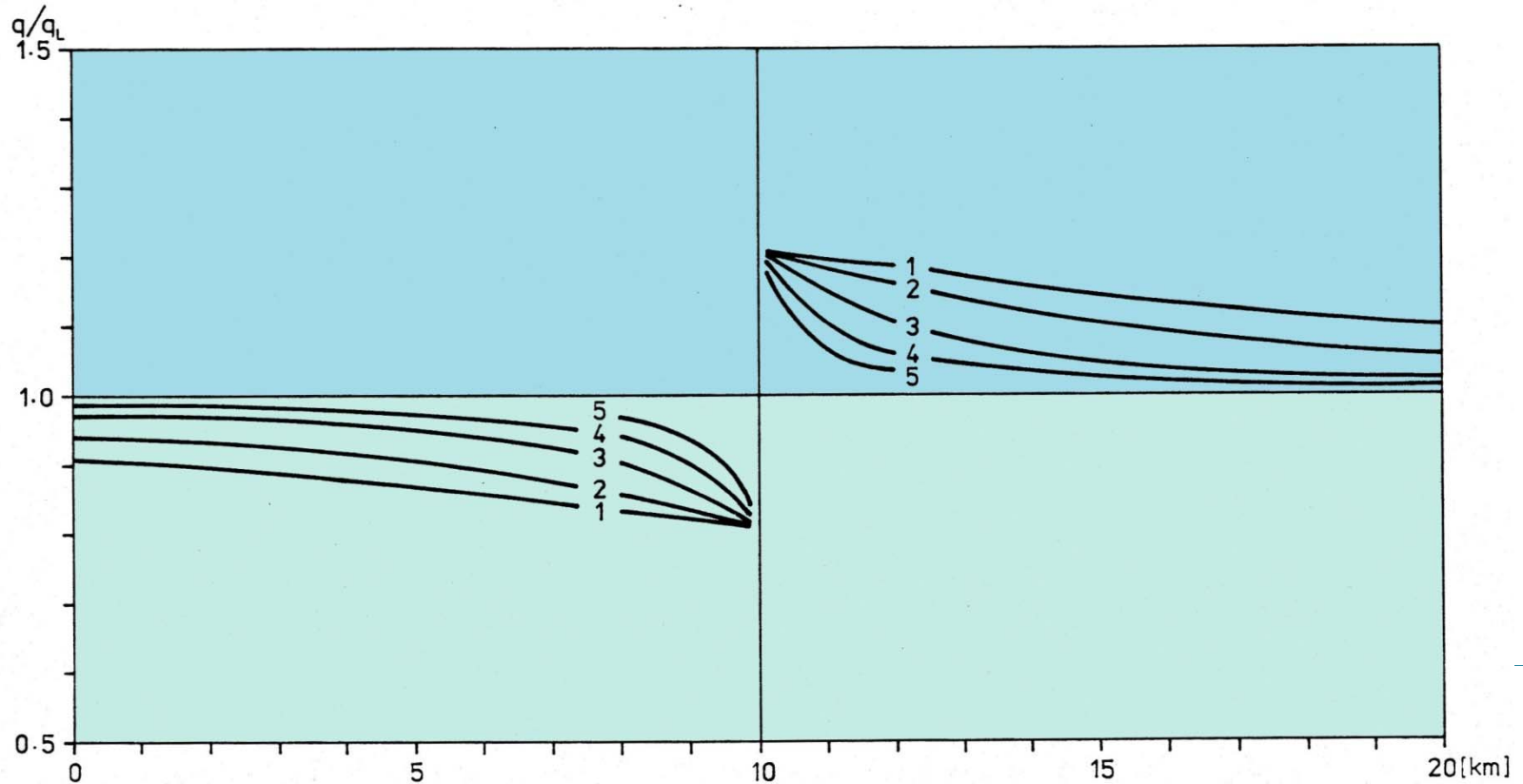
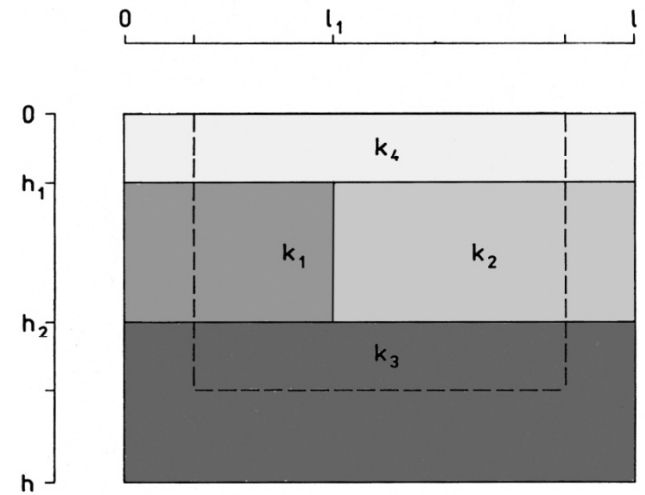
Modely refrakcie tepelného toku a modely zdrojových anomálií ukázali, že v oblasti Západných Karpát a okolitých jednotkách sú jednotlivé modelovacie prístupy najviac citlivé na refrakčné efekty a to od zostavenia štrukturálneho modelu až po použitie kontrolných dát.

# Ďakujem za pozornosť!



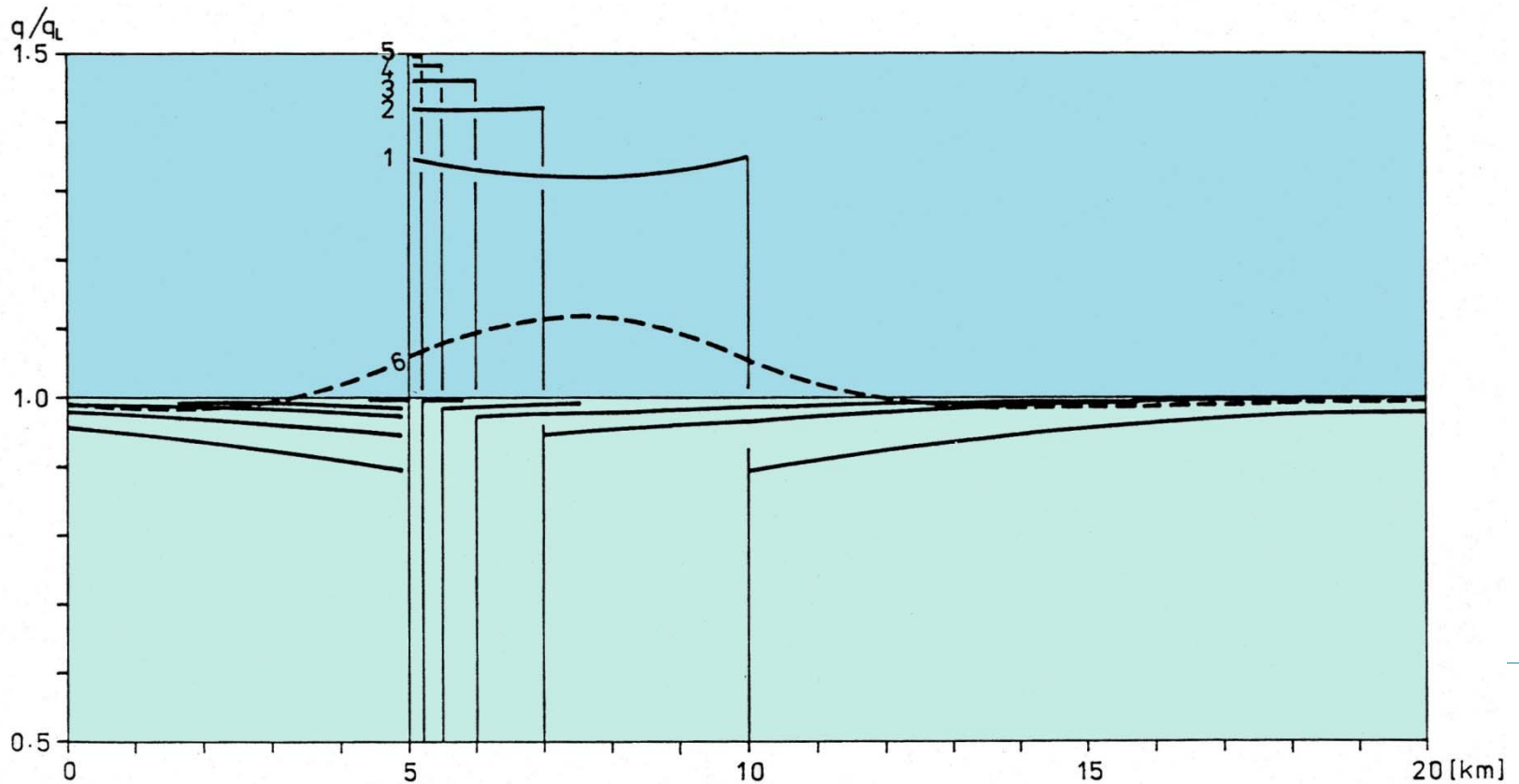
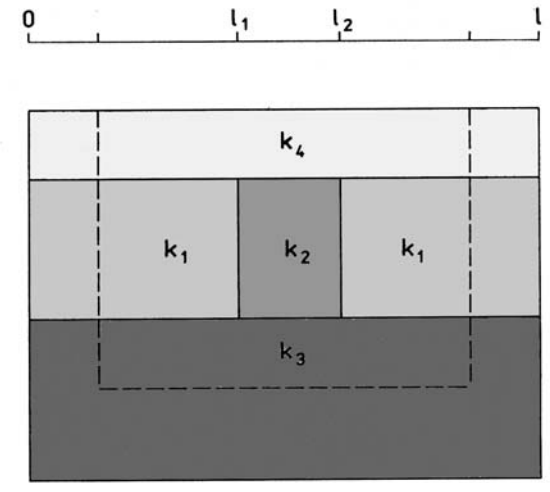
Relative surface heat flow density distributions  
 for models without covering layer ( $h_1 = 0$ ); with fixed  
 thermal conductivity contrast  $k_2 / k_1 = 3.00/2.00$   
 and changing depth parameter  $h_2$ :

- 1 10000 m
- 2 5000 m
- 3 2000 m
- 4 1000 m
- 5 500 m



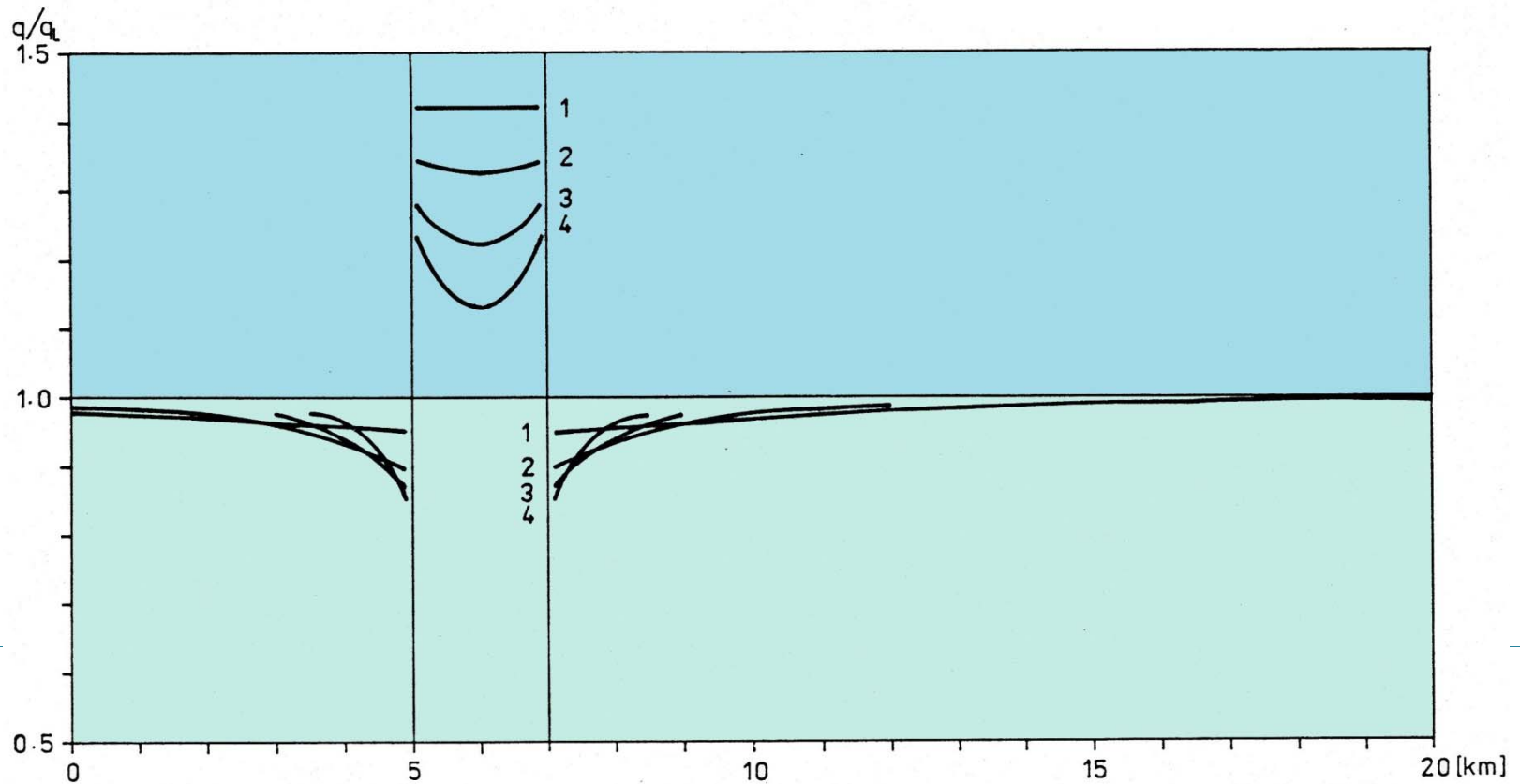
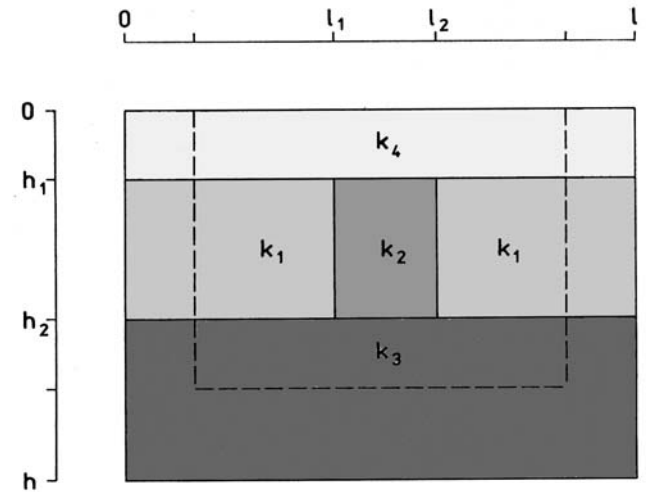
Relative surface heat flow density distributions for models without covering layer ( $h_1 = 0$ , solid lines) or having the cover ( $h_1 = 2000$  m, dashed lines); with fixed value  $h_2 = 5000$  m and thermal conductivity contrast  $k_2 / k_1 = 3.00/2.00$ . The width of anomalous body  $b = l_2 - l_1$  was changed

|     |              |   |              |   |             |
|-----|--------------|---|--------------|---|-------------|
| 1,6 | $b = 5000$ ; | 2 | $b = 2000$   |   |             |
| 3   | $b = 1000$ ; | 4 | $b = 1000$ ; | 5 | $b = 500$ m |



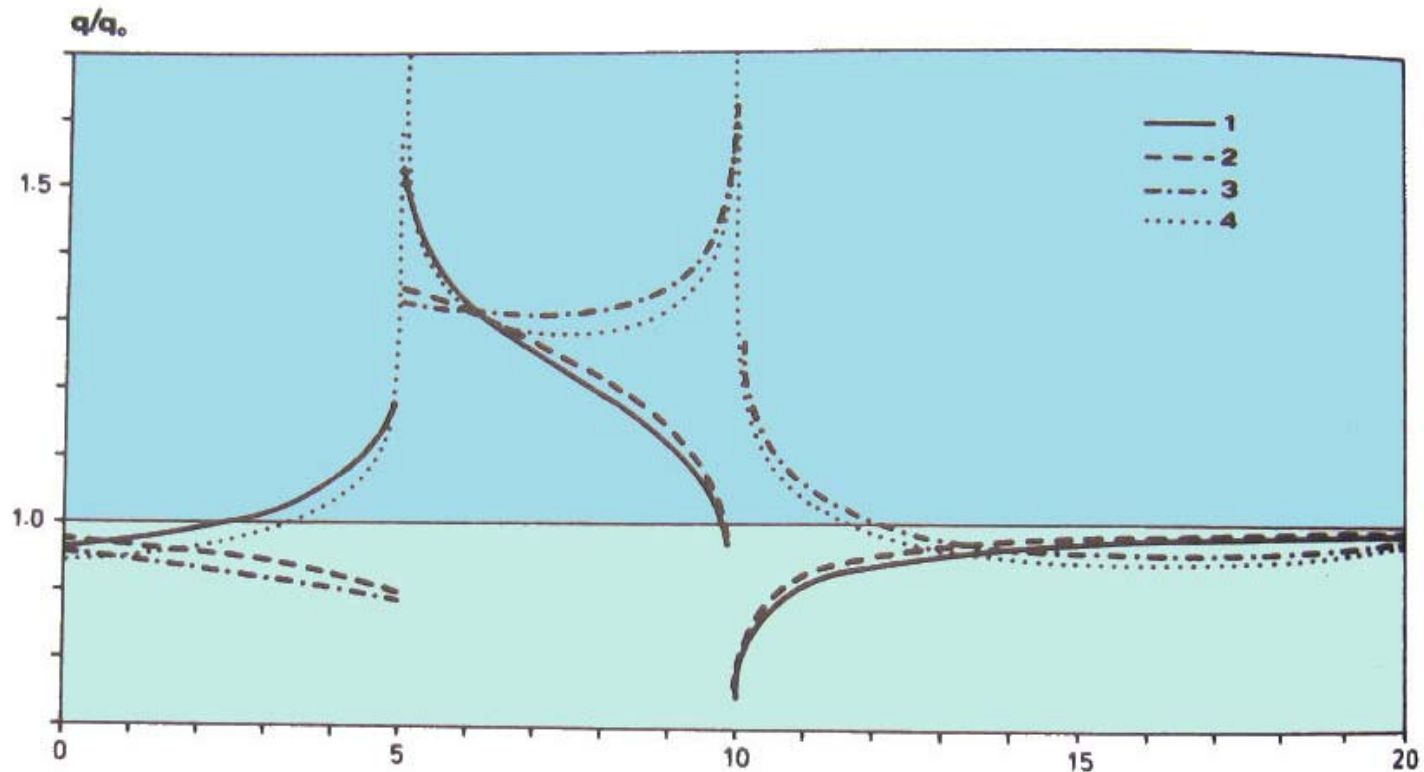
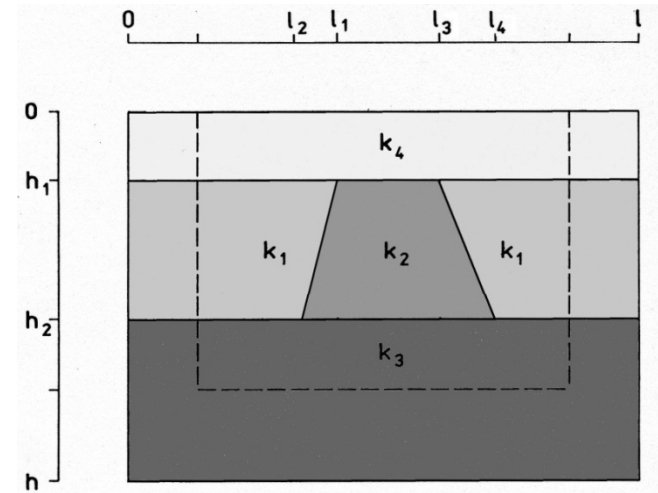
Relative surface heat flow density distributions for models without covering layer ( $h_1 = 0$ ) with fixed width  $l_2 - l_1 = 2000$  m and thermal conductivity contrast  $k_2 / k_1 = 3.00/2.00$ . The height of anomalous body  $h_2$  was changed

- |   |                |   |               |
|---|----------------|---|---------------|
| 1 | $h_2 = 5000$ ; | 2 | $h_2 = 2000$  |
| 3 | $h_2 = 1000$ ; | 4 | $h_2 = 500$ m |

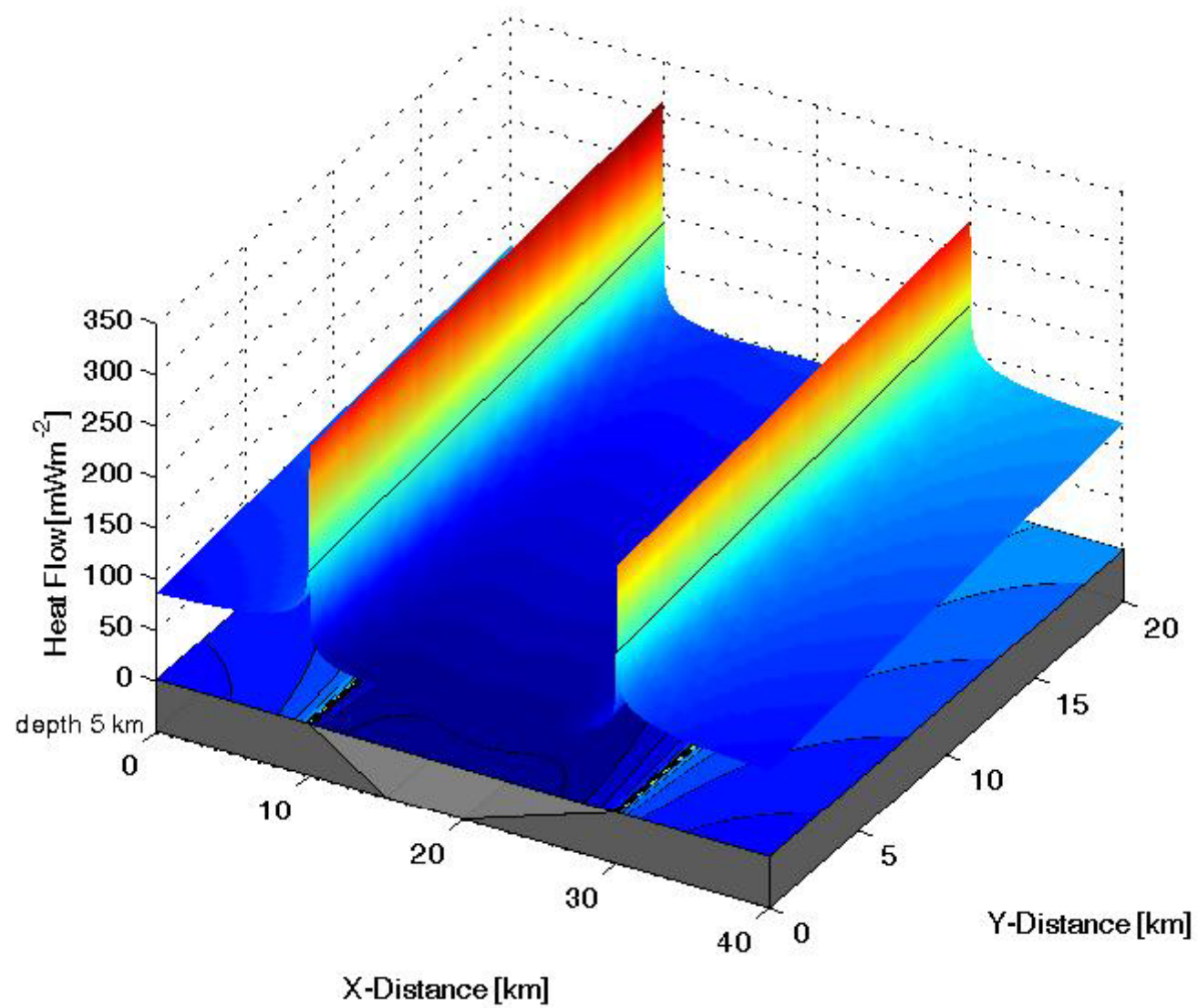


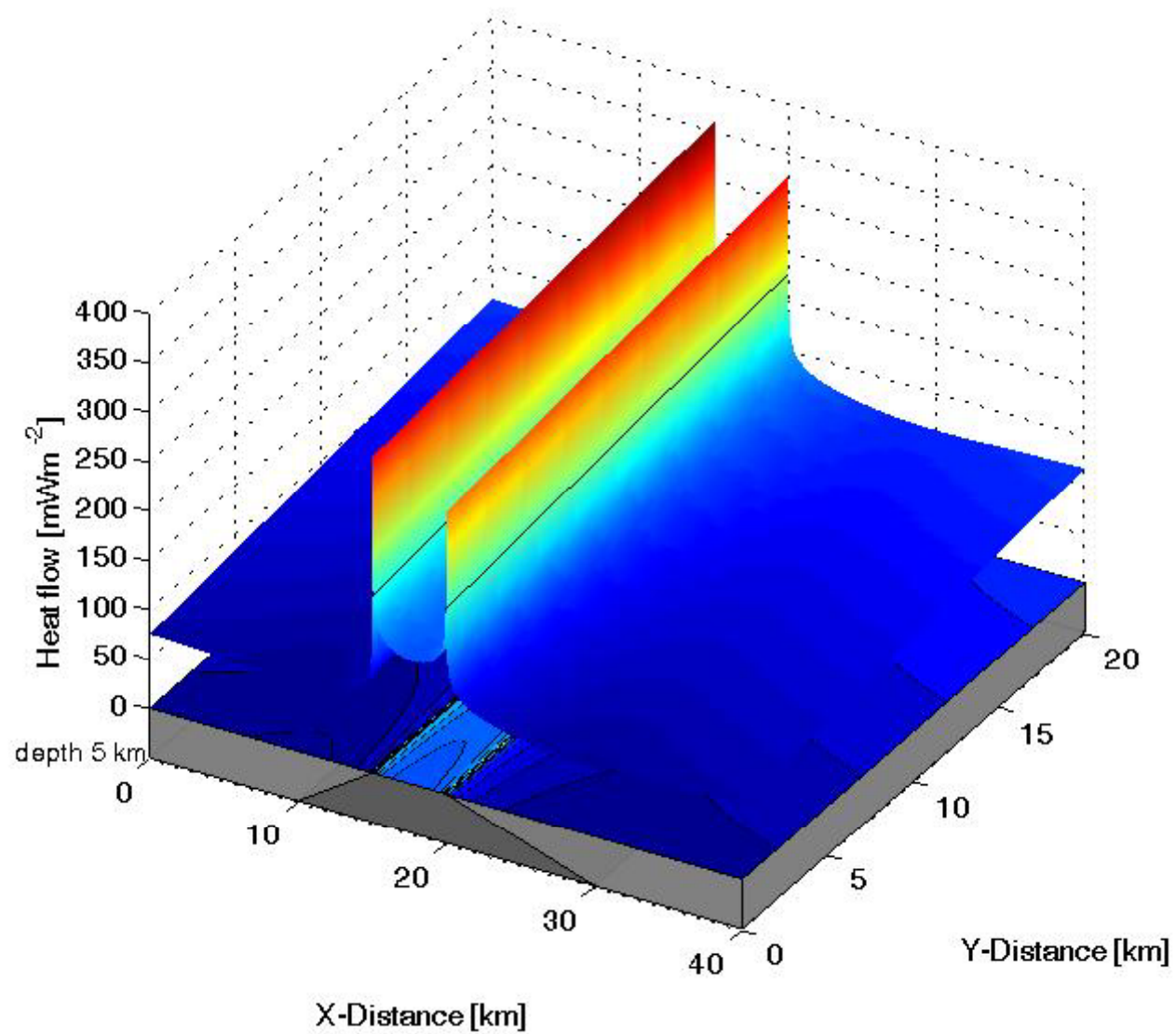
Relative surface heat flow density distributions for models without covering layer ( $h_1 = 0$ ); with fixed value  $h_2 = 5000$  m; thermal conductivity contrast  $k_2 / k_1 = 3.00/2.00$ . The angles of lateral contact lines was changed to receive various geological structures aslant layer, basins, horsts....

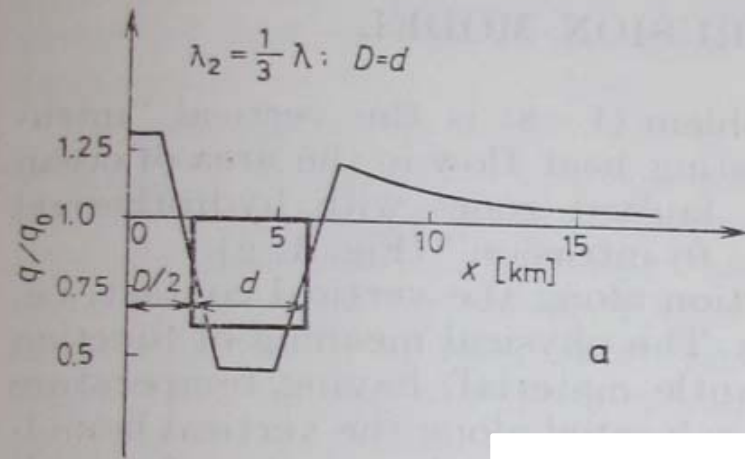
1 // 2 || 3 |\ 4 /\











!!!  
Step change ...

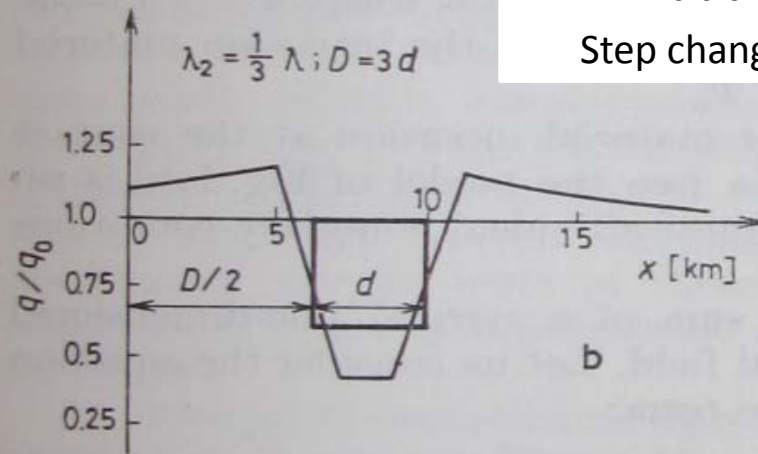


Fig. 8. Effect of  $D$ -distance between two squared "valleys" ( $H = 0$ ) of equal thermal conductivities ( $\lambda_2 = \lambda_3 = 1/3 \lambda_1$ ) on surface heat flow a -  $D = d$ ;  
b -  $D = 3d$

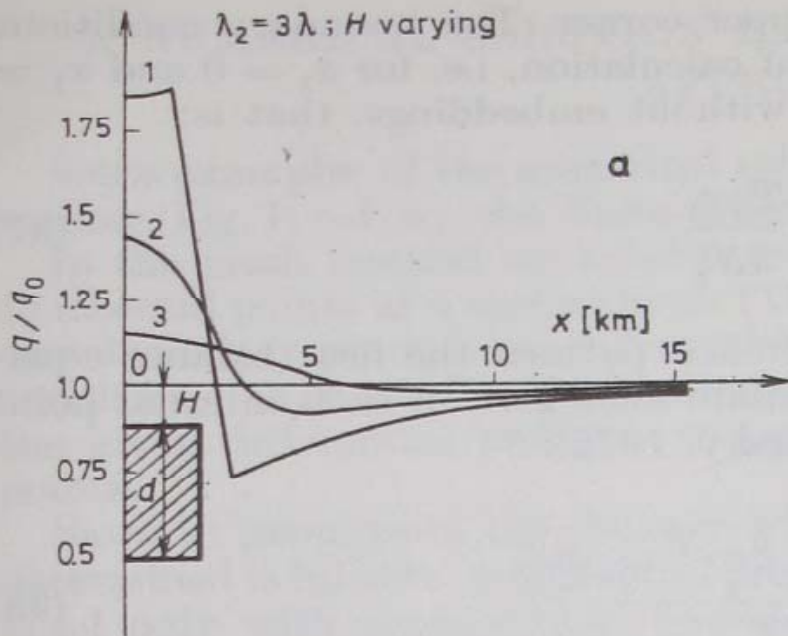
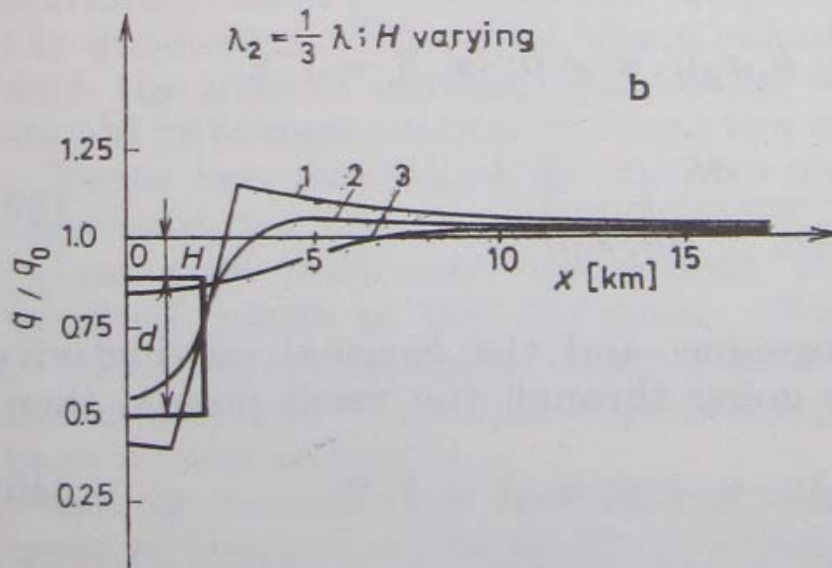


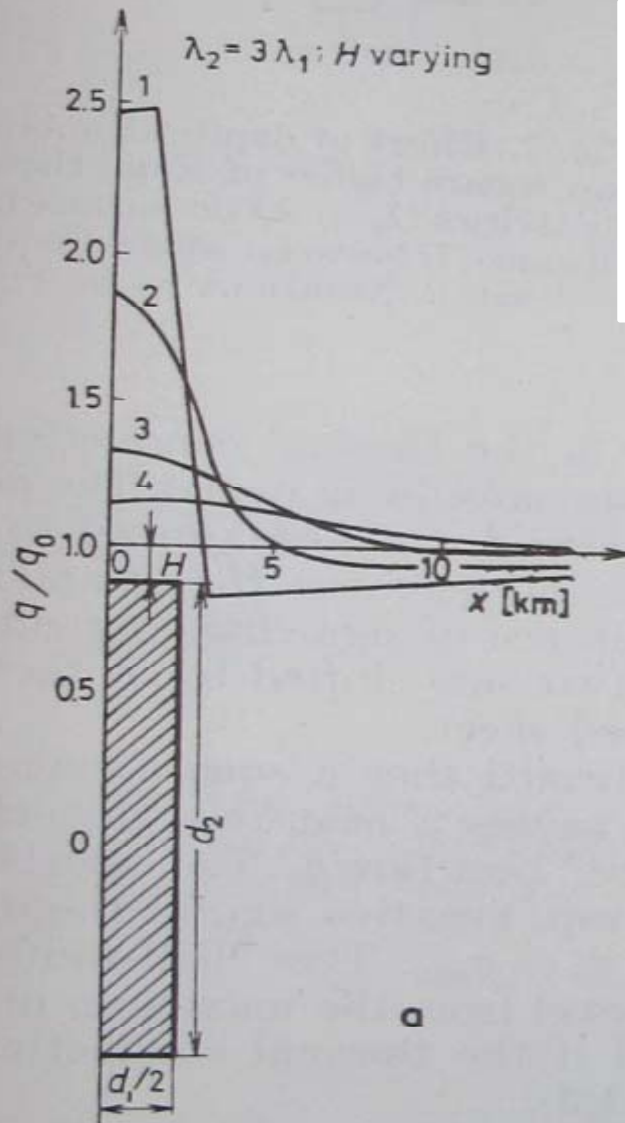
Fig. 4. Effect of depth of submersion of a square body on heat flow values  
 a - conducting body:  $\lambda_2 = 3\lambda_1$ ;  
 b - insulating body:  $\lambda_2 = 1/3 \lambda_1$ .  
 Notations:  $q = q_0 + q_{\text{add}}$  - total heat flow;  $q/q_0$  - relative heat flow;  $q_0$  - normal heat flow without any embedding; square side  $d = 4 \text{ km} = 4h$ ; mesh spacing  $h = 1 \text{ km}$ . Distance  $H$  from the upper edge of body to the surface is:

- 1 -  $H = 0$ ; 2 -  $H = h \text{ km}$ ;  
 3 -  $H = 4h \text{ km}$



!!!

Step change of surface heat flow density at corners of body laying at surface



!!!  
Step change of surface heat flow density at corners of body laying at surface

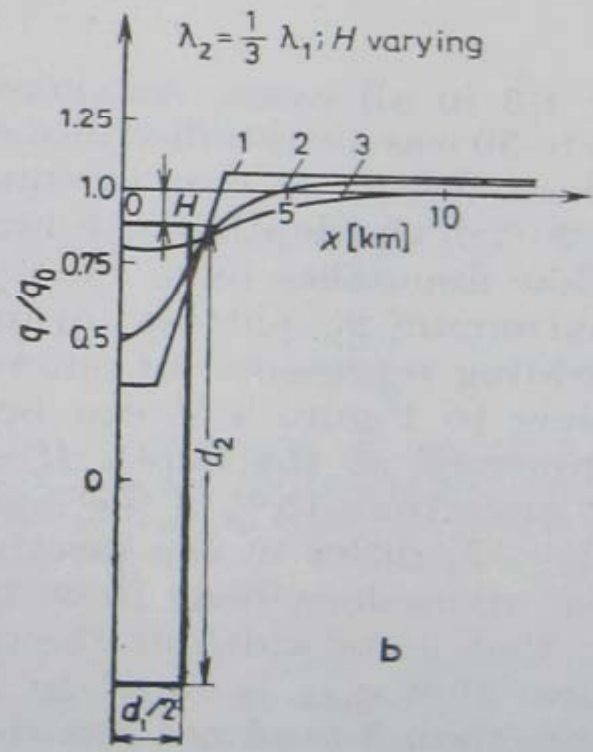
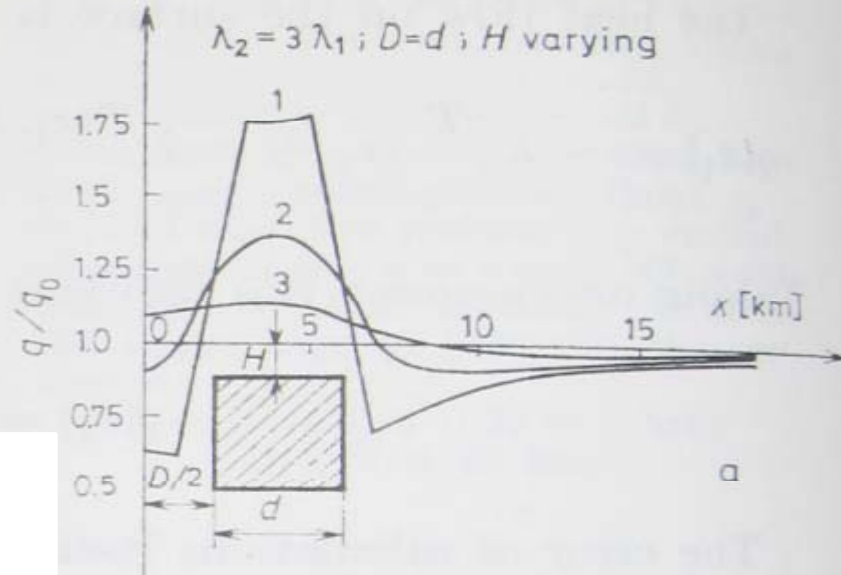
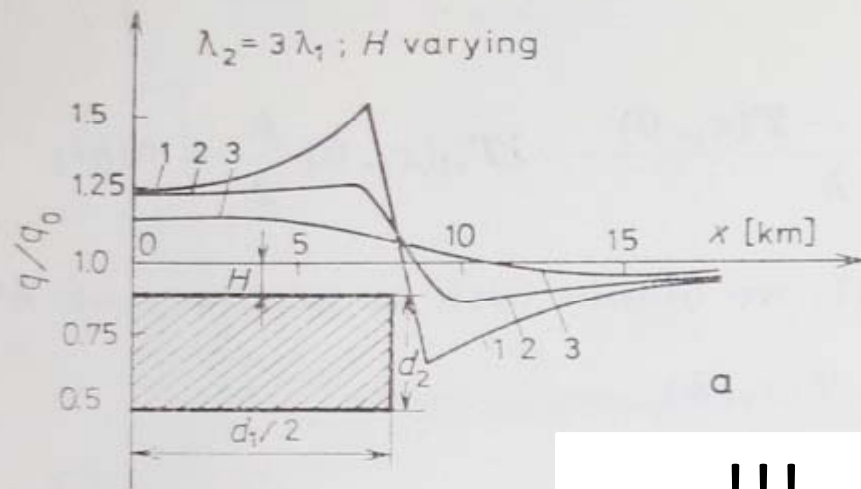


Fig. 5. Effect of depth of submersion of a vertical rectangle on surface heat flow: a - conducting body:  $\lambda_2 = 3\lambda_1$ ; b - insulating body:  $\lambda_2 = 1/3 \lambda_1$ . Notations as in Fig. 4, and 4 -  $H = 8$  km. Rectangle sides:  $d_1 = 4$  km;  $d_2 = 16$  km



!!!  
Step change ...

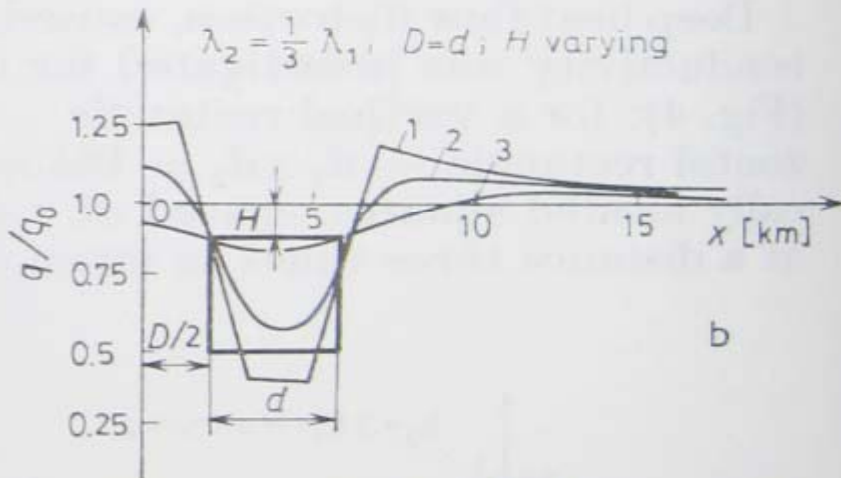
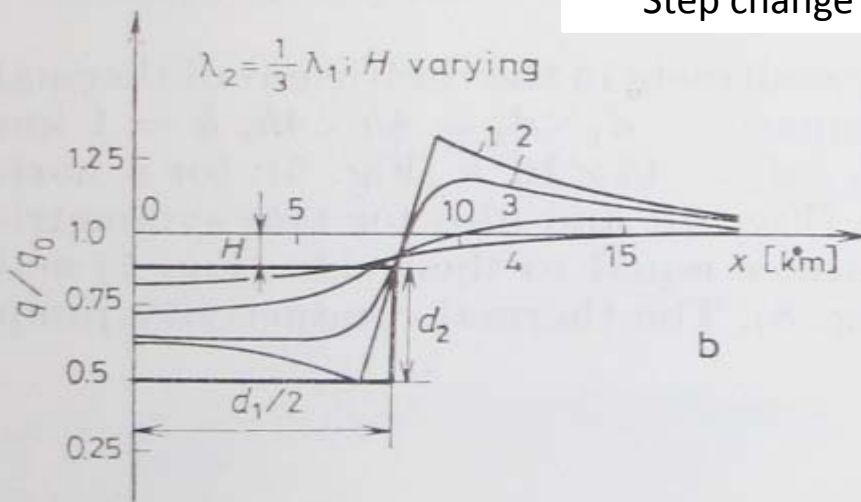
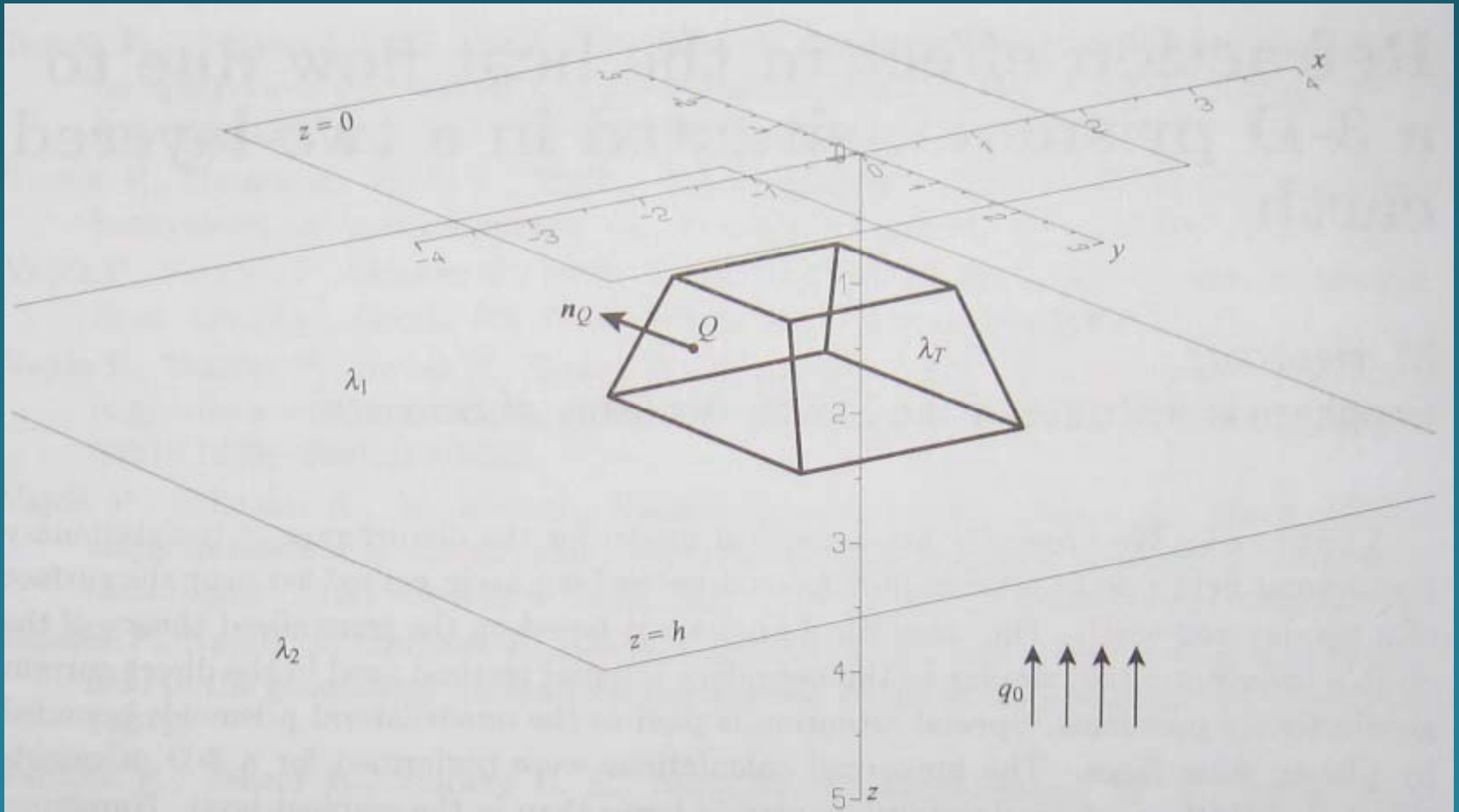


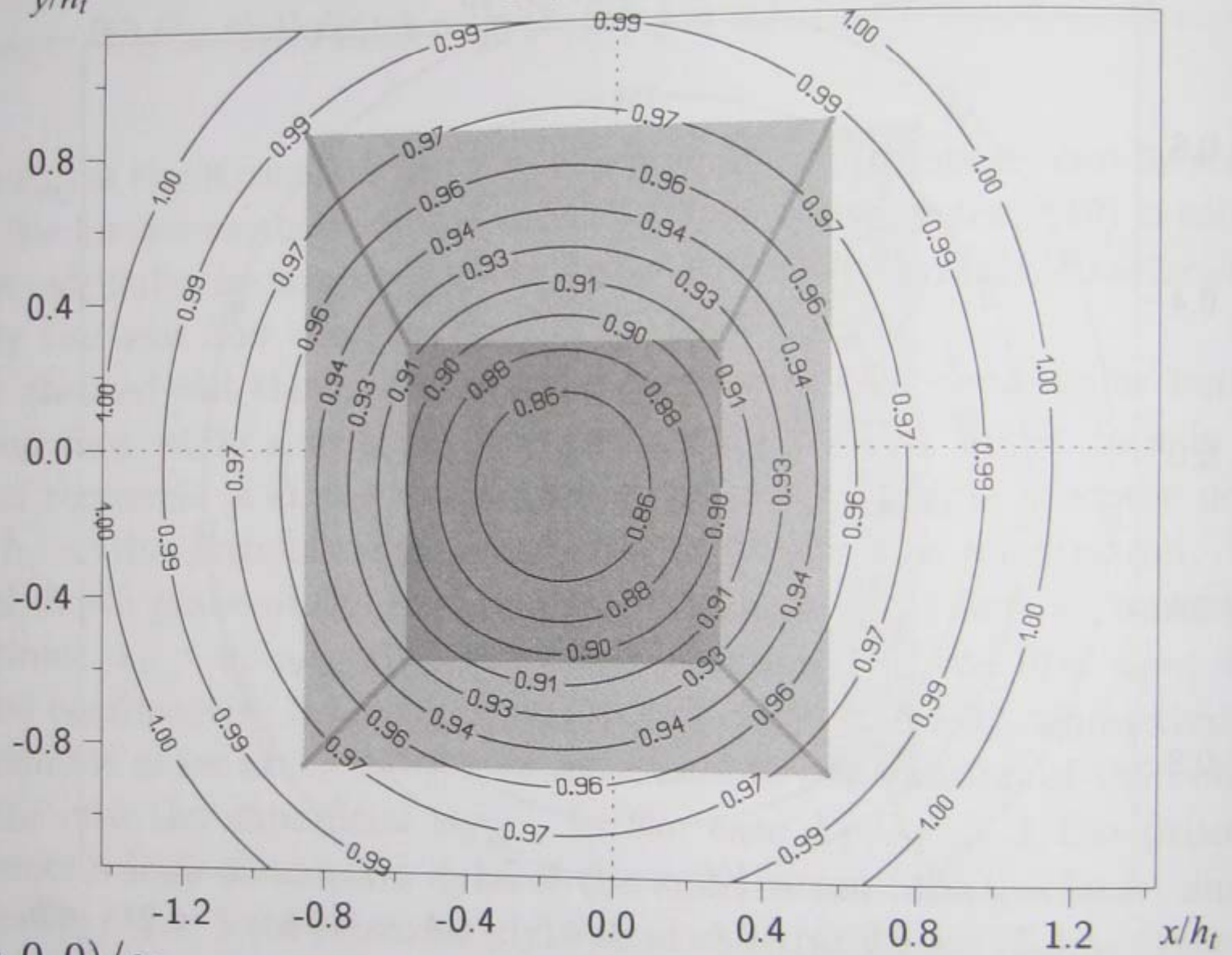
Fig. 6. Effect of depth of submersion of a horizontal rectangle on surface heat flow. Notations as in Figs 4 and 5. Rectangle sides:  $d_1 = 16$  km,  $d_2 = 4$  km

Fig. 7. Effect of depth of submersion of two square bodies of equal thermal conductivities ( $\lambda_2 = \lambda_3$ ) on surface heat flow. Distance  $D$  between squares equals their side  $d$ . Notations as in Fig. 4



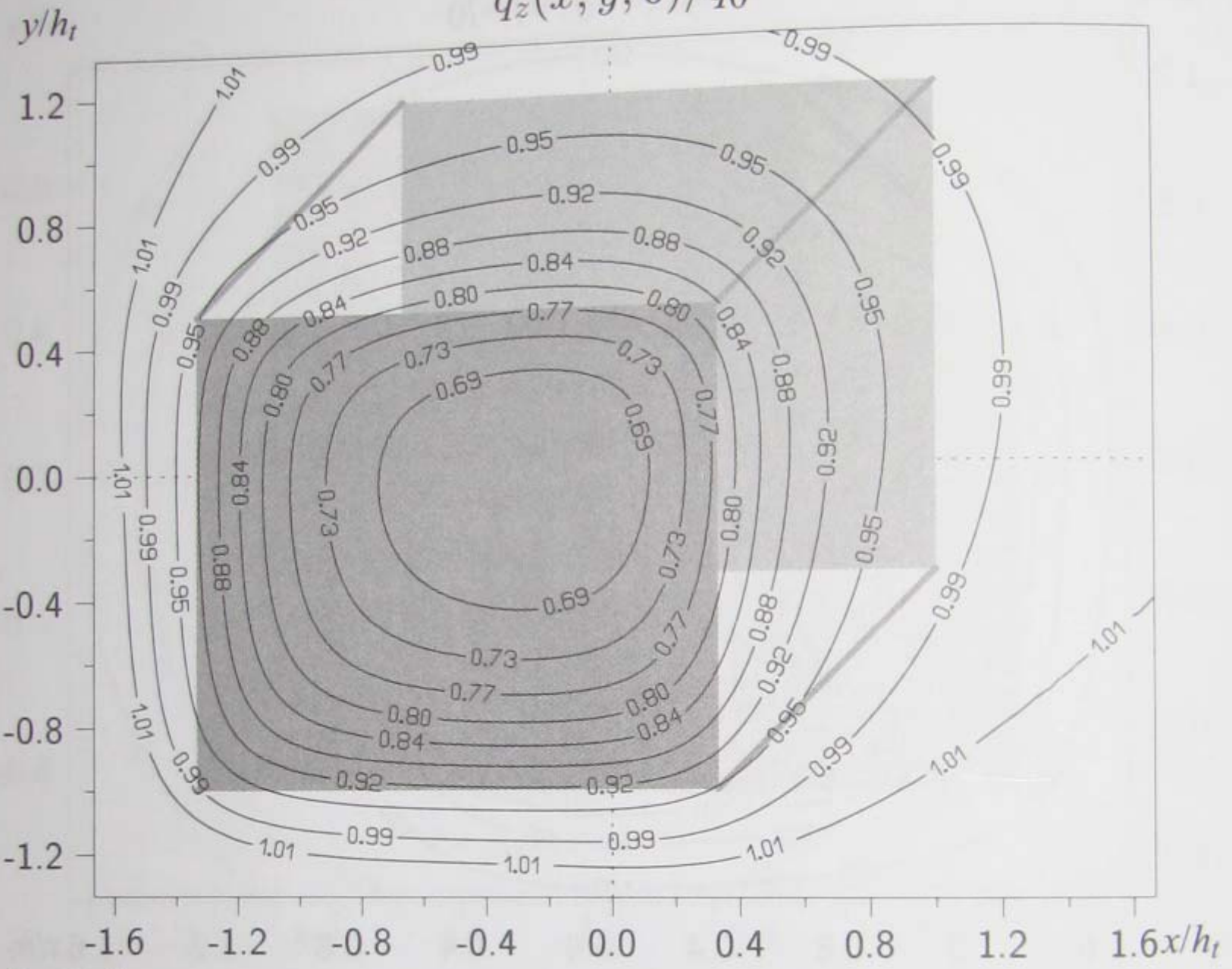
3D polyhedral body

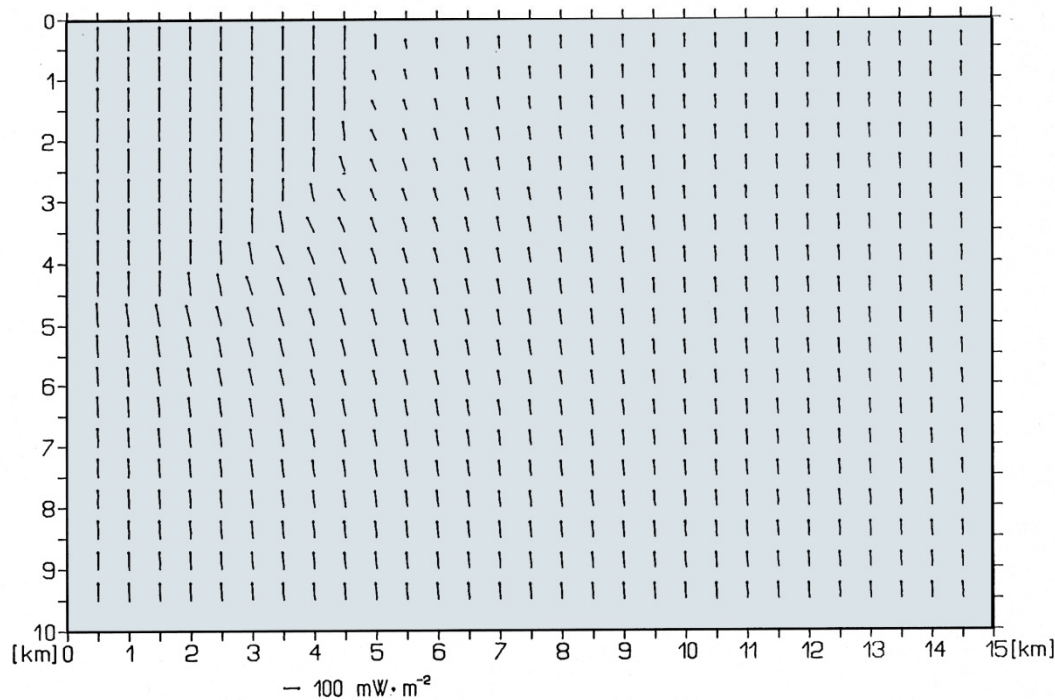
$$q_z(x, y, 0)/q_0$$

 $y/h_t$  $q_z(x, 0, 0)/q_0$  $x/h_t$



$$q_z(x, y, 0)/q_0$$



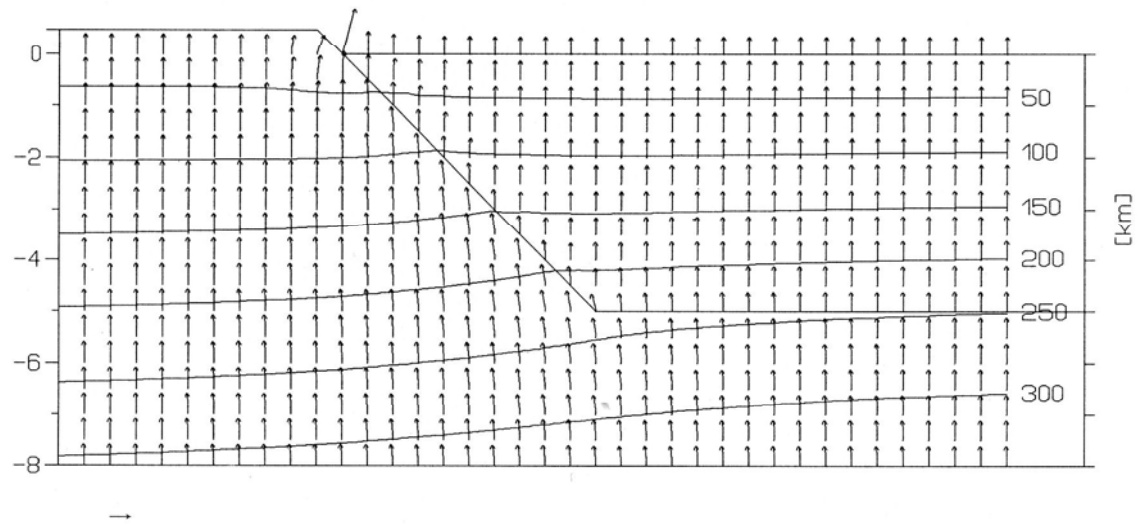
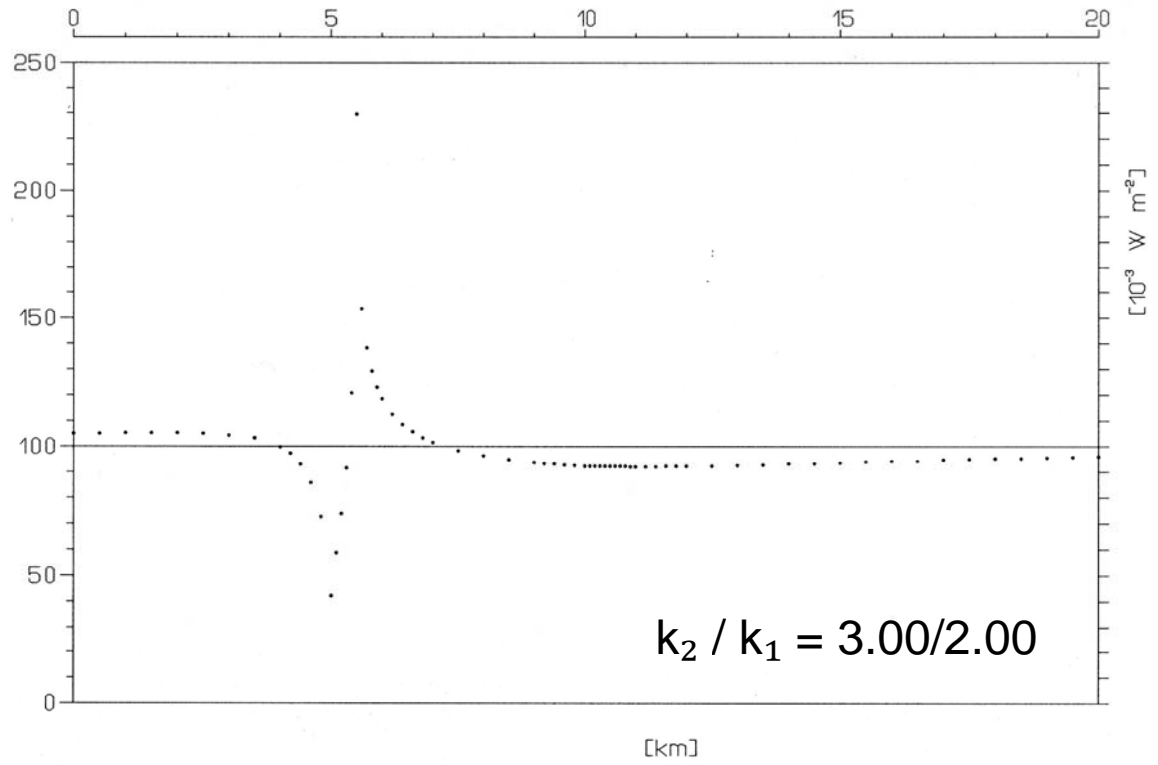


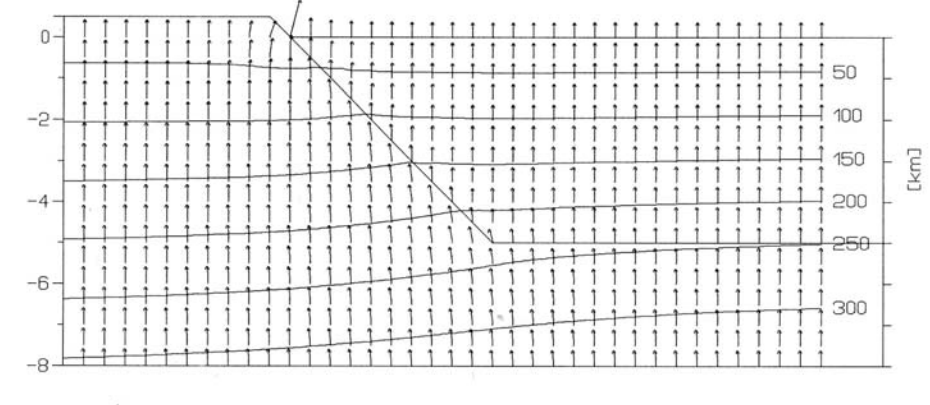
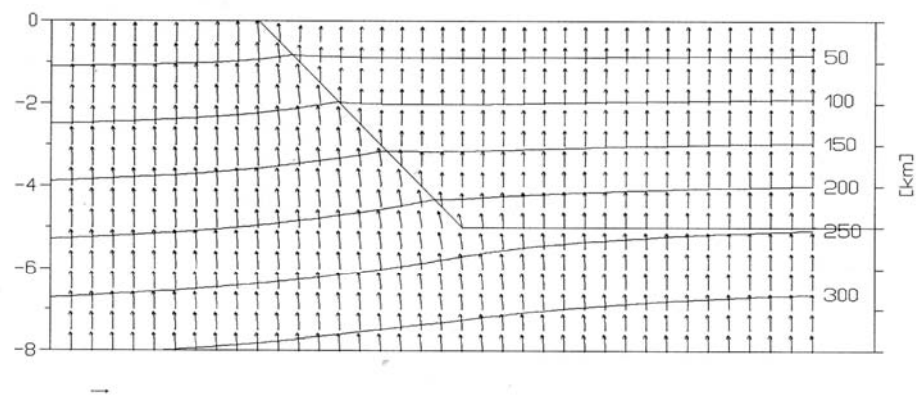
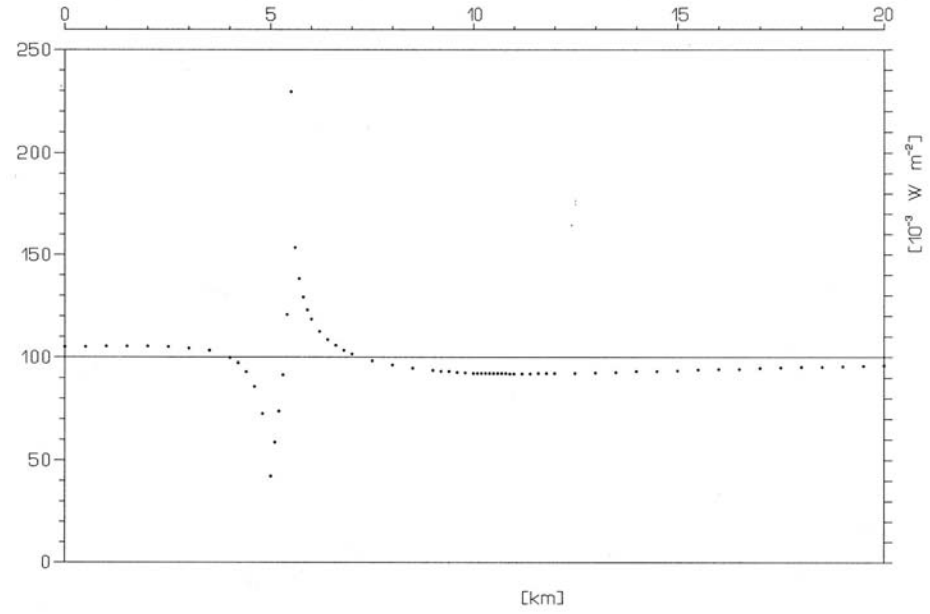
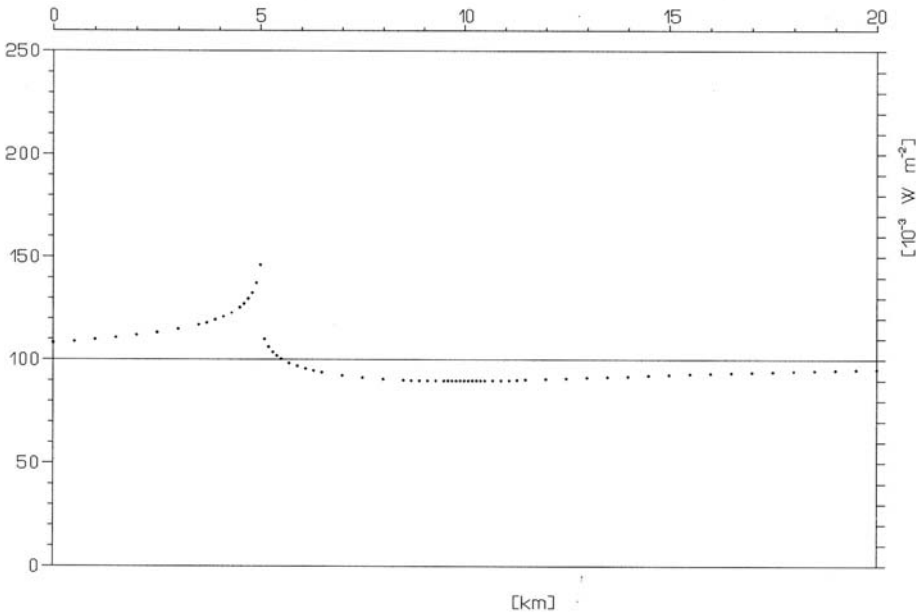
Heat flow density distribution

< - - - - -

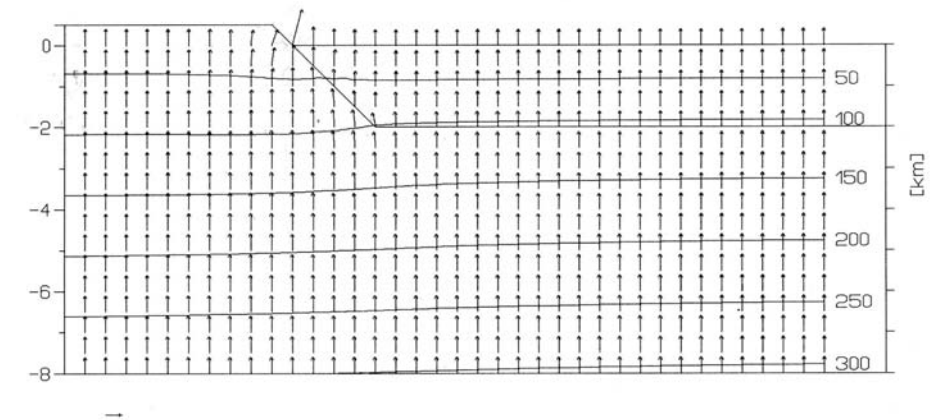
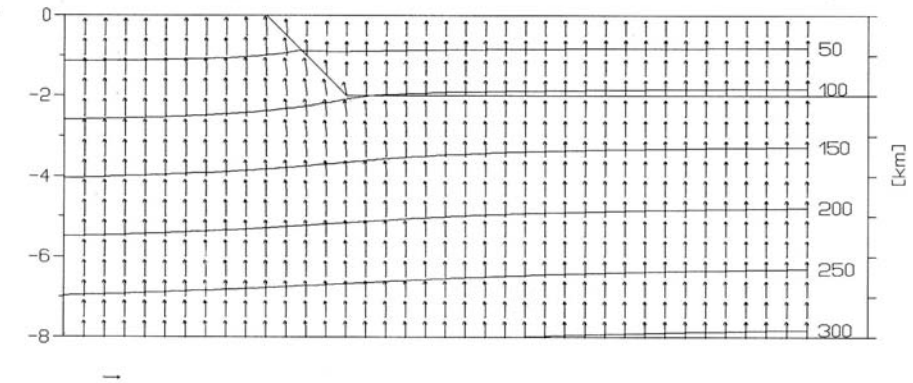
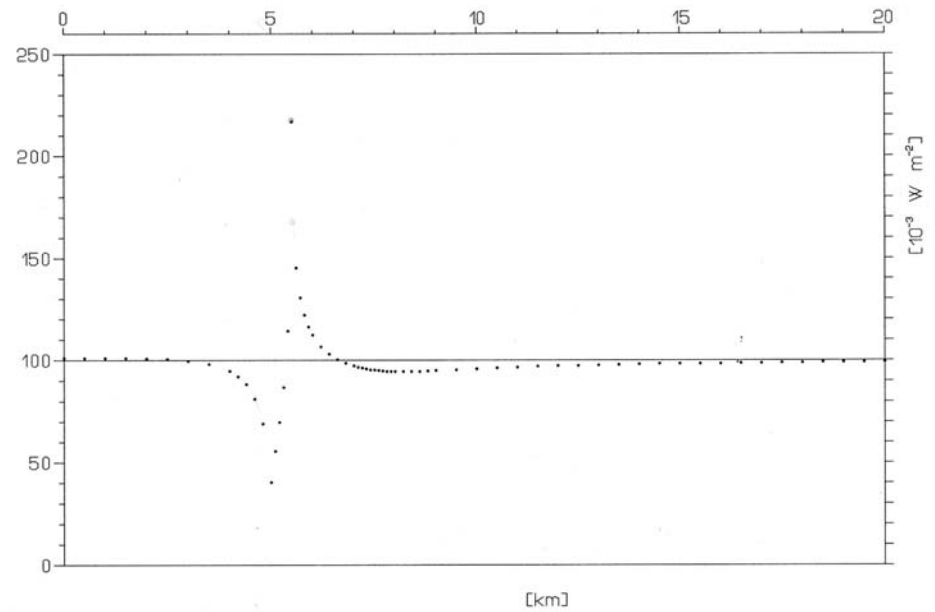
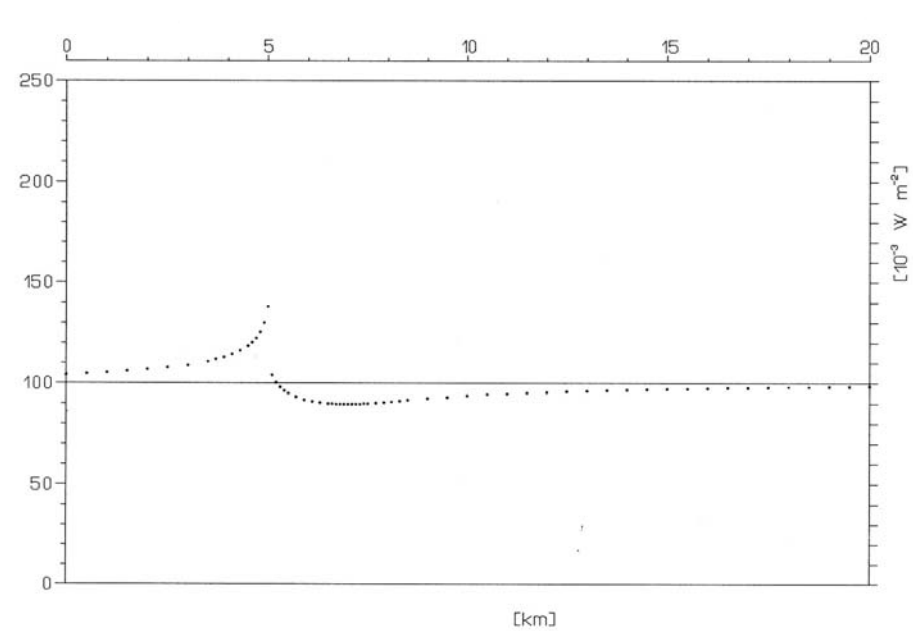
Surface heat flow  $q(x)$  definition for horizontal coordinate  $x$  and from original heat flow density at lower boundary of model

$$q(x) = \begin{cases} q_0 \left( 1 + \frac{1 - k_2/k_1}{1 + k_2/k_1} \frac{a^2}{x^2} \right), & |x| > a, \\ q_0 \left( 2 \frac{k_2/k_1}{1 + k_2/k_1} \right), & |x| < a, \end{cases}$$

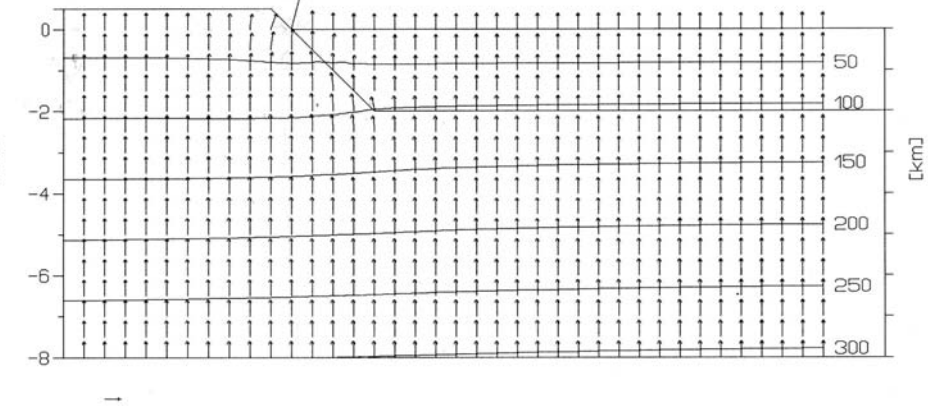
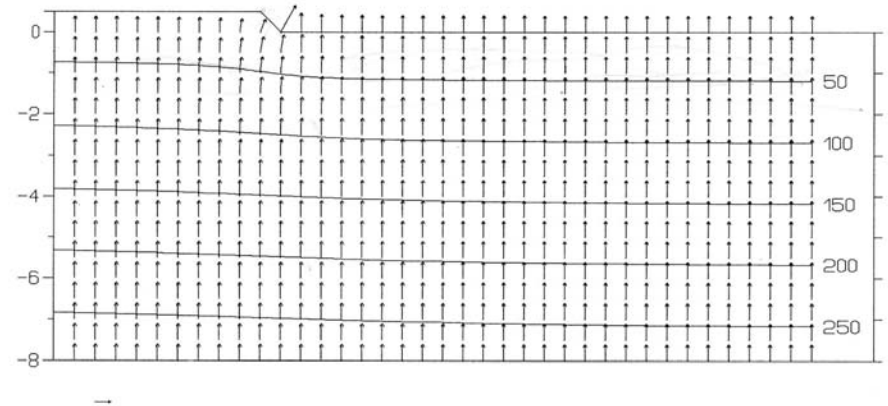
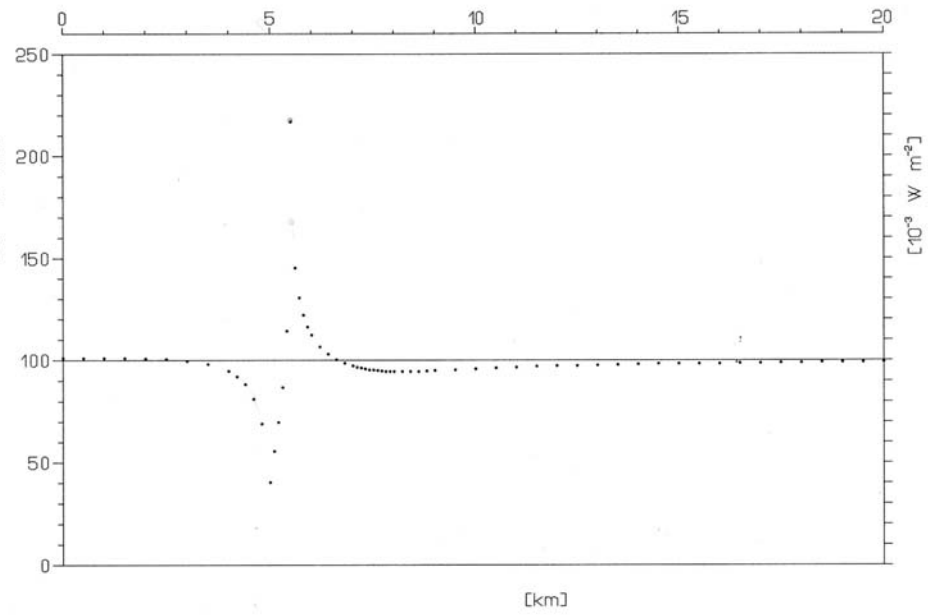
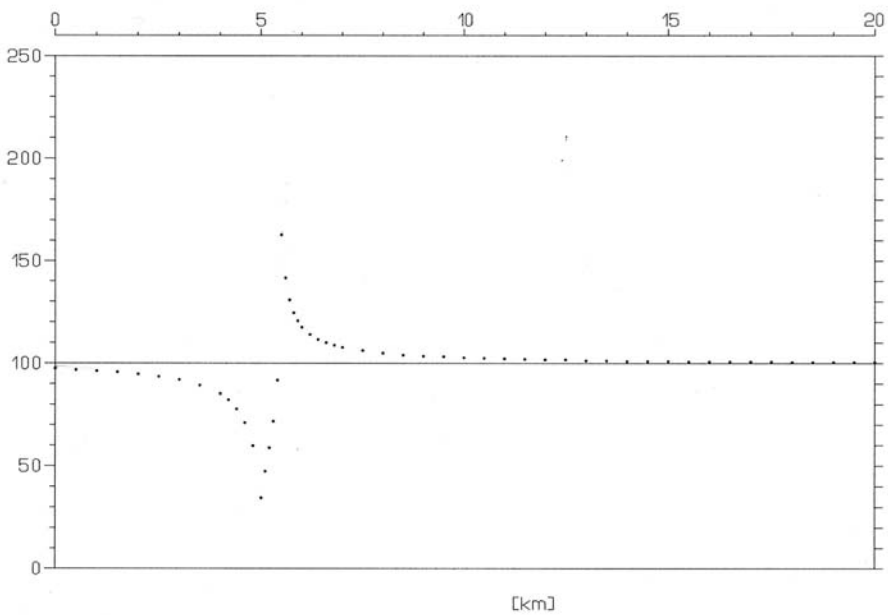




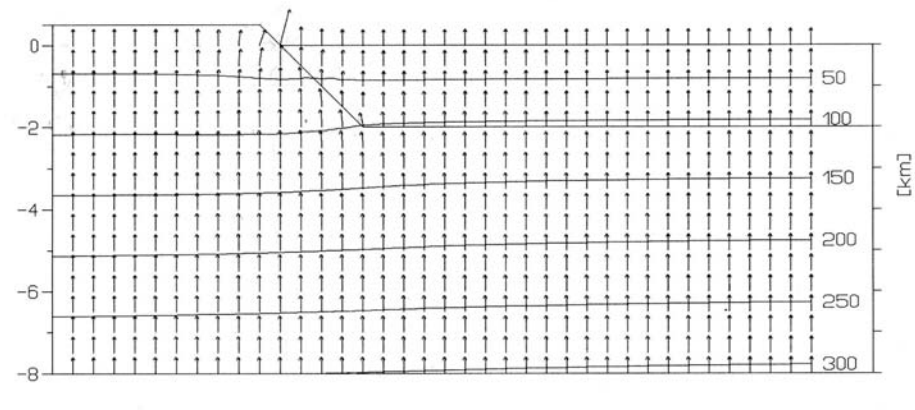
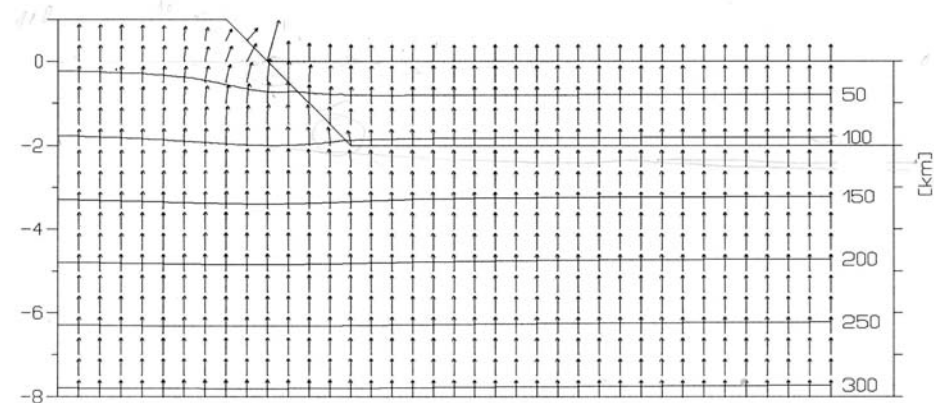
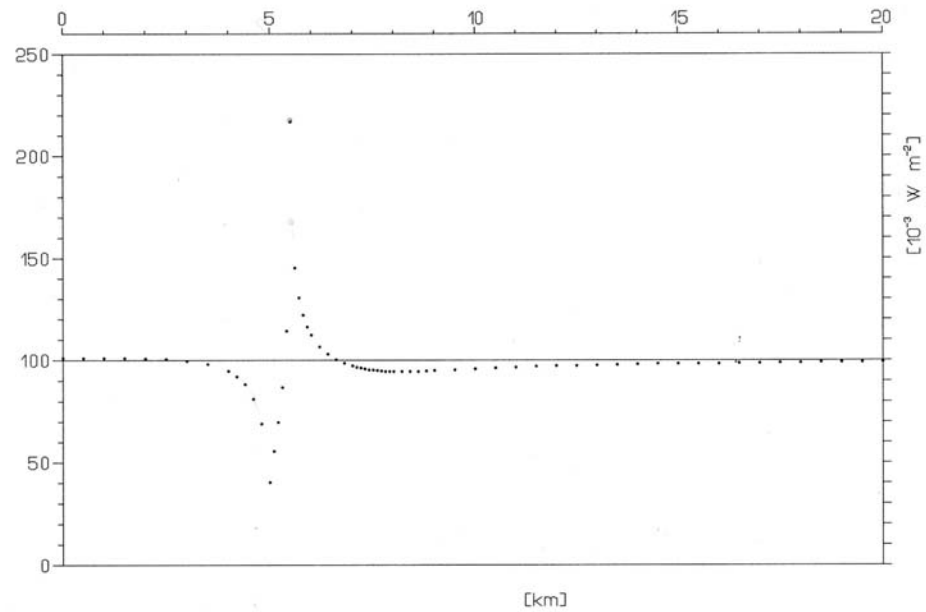
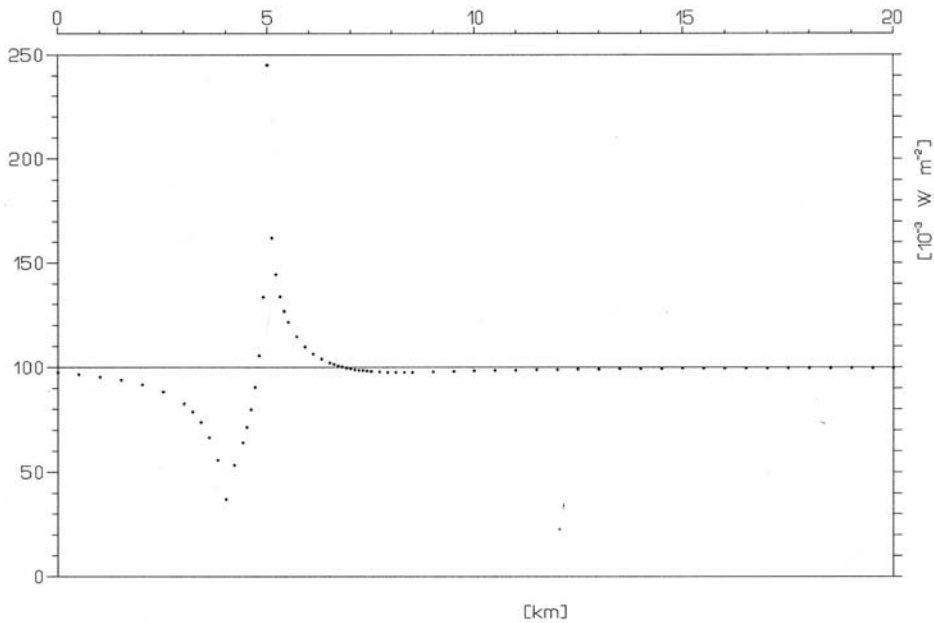
Comparison of basin models with and without topography. (basin depth 5000 m, topo 500 m)



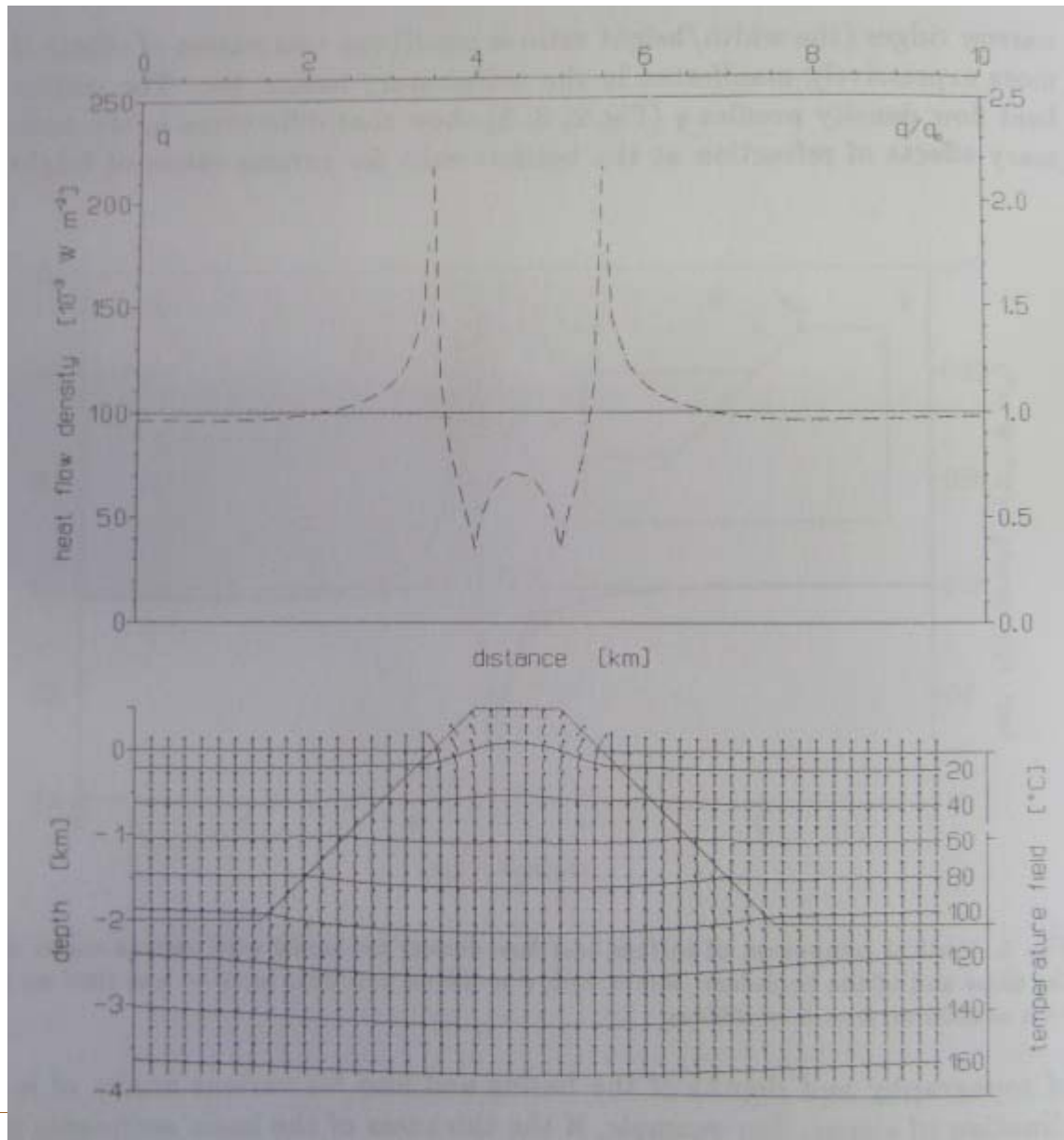
Comparison of basin models without and with topography. (depth 2000 m, topo 500 m)



Comparison of topography models without and with basin. (basin depth 2000 m, topo 500 m)

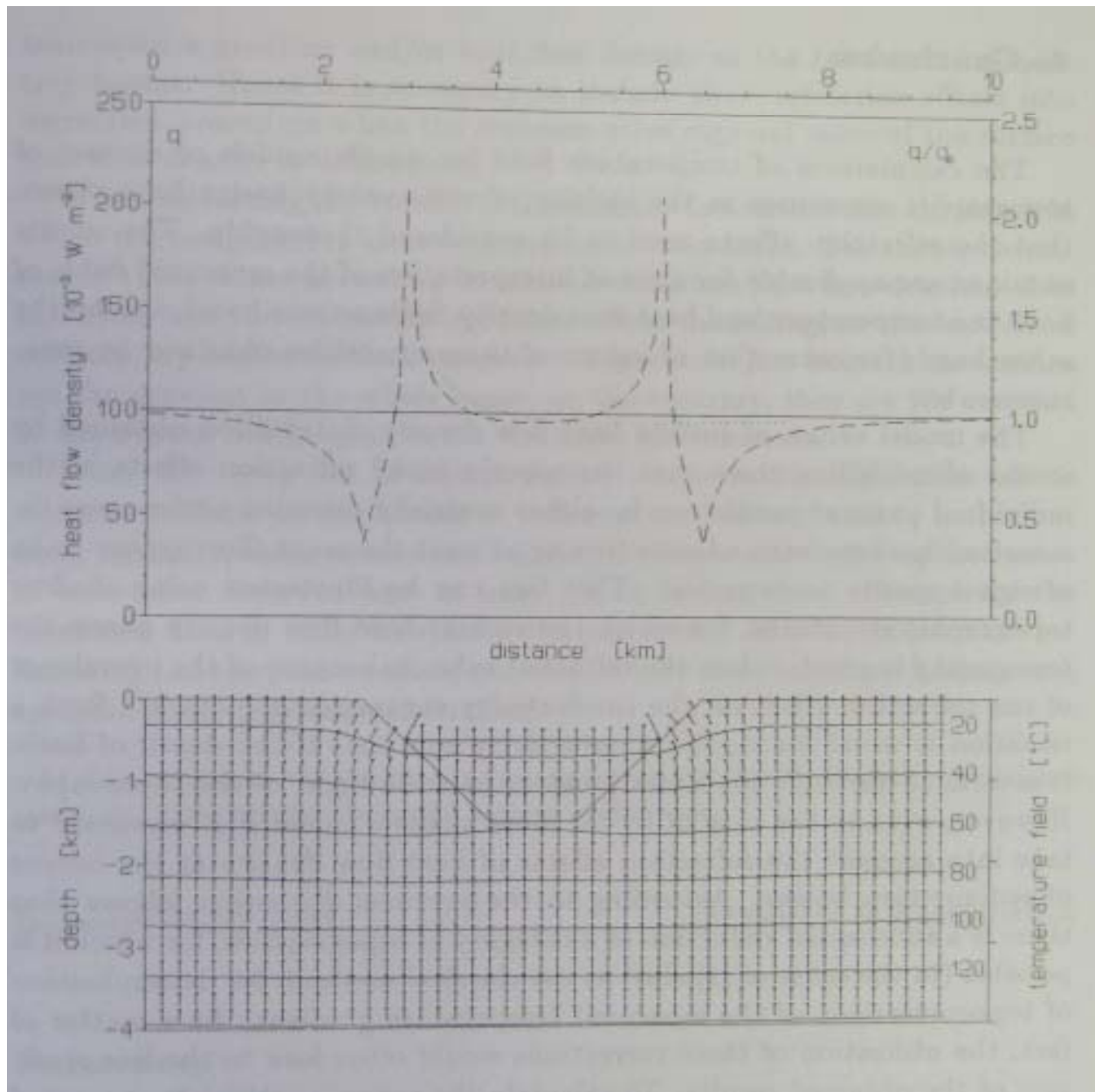


Comparison of basin models with topography 1000 m and 500 m. (basin depth 2000 m)



Mountain ridge between two basins





Intramountain basin model

# Real models

