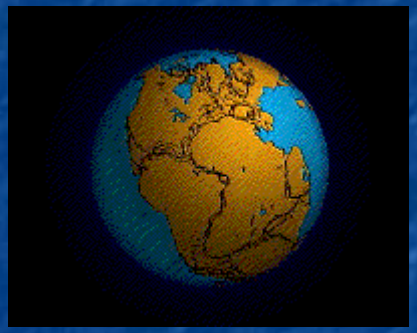
Trzęsienia ziemi



Marek Grad
Instytut Geofizyki, Wydział Fizyki
Uniwersytet Warszawski

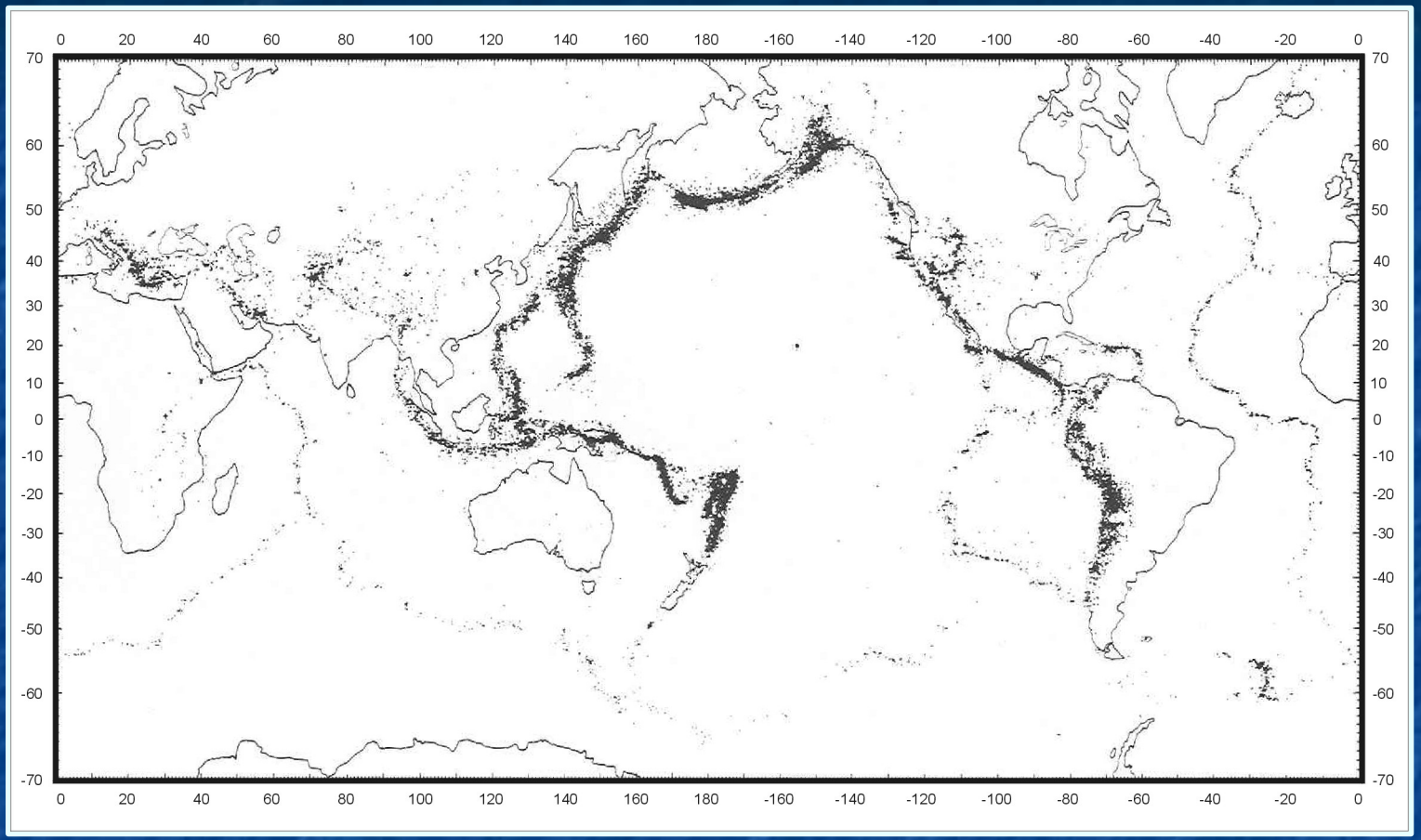
Wykład z cyklu "Fizyka we Współczesnym Świecie"
SDD, 1.10.2009

kontynuacja wykładu inauguracyjnego, jest pretekstem do opowiedzenia o budowie Ziemi i procesach w jej wnętrzu, oraz czym zajmujemy się na naszym wydziale ...

- **Trzęsienia ziemi, fale sejsmiczne i budowa wnętrza Ziemi**
- **Skorupa ziemska, płaszcz, jądro**
- **Eksperymenty sejsmiczne**
- **Przemieszczające się kontynenty – teraz i w przeszłości**
- **Pole magnetyczne Ziemi**
- **Procesy we wnętrzu Ziemi, konwekcja, dryf kontynentów**
- **Przyszłość dryfujących kontynentów**

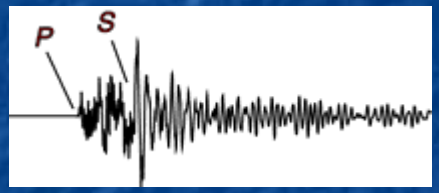
Trzęsienia ziemi, fale sejsmiczne i budowa wnętrza Ziemi

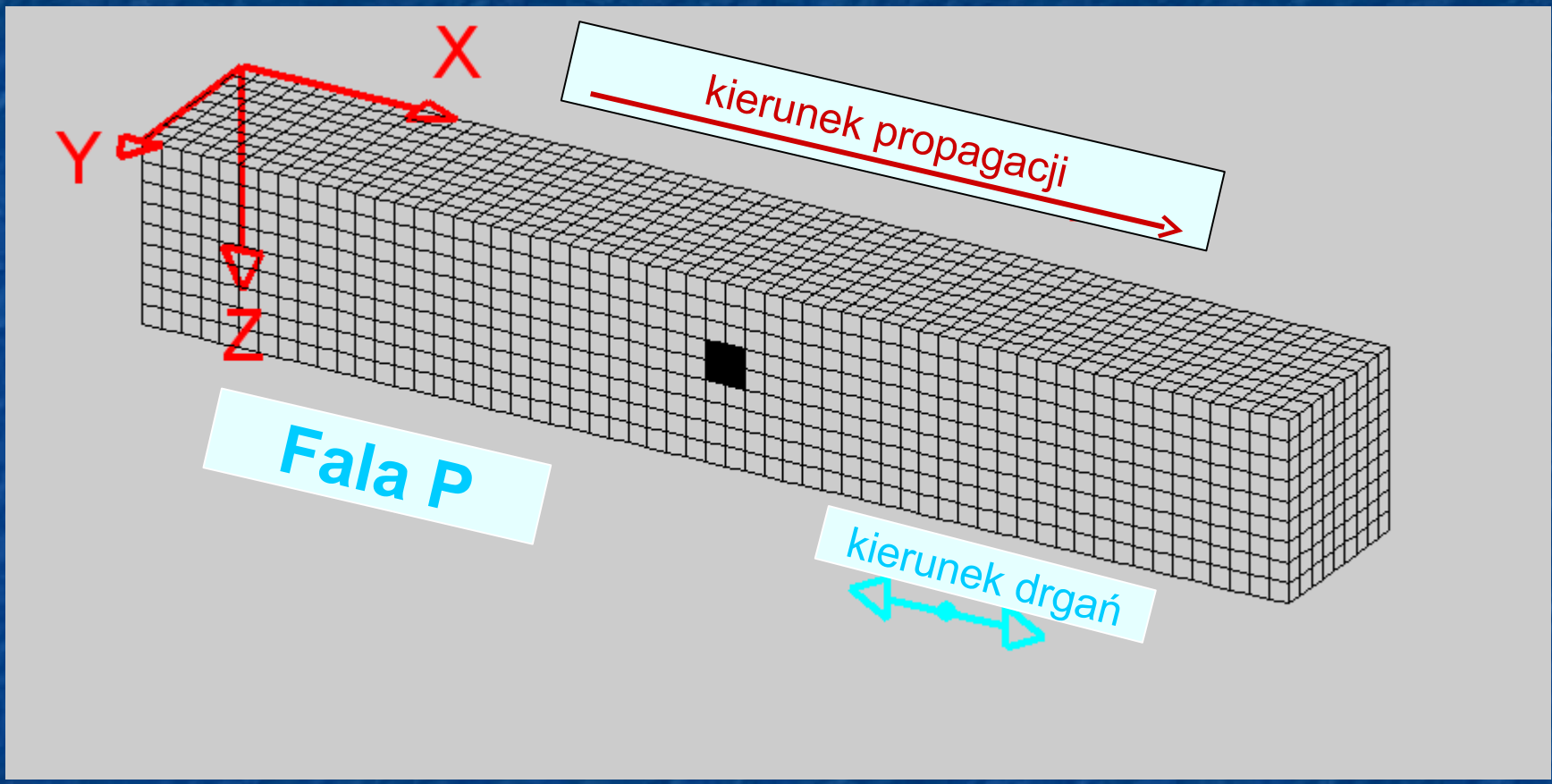
Sejsmiczność Ziemi

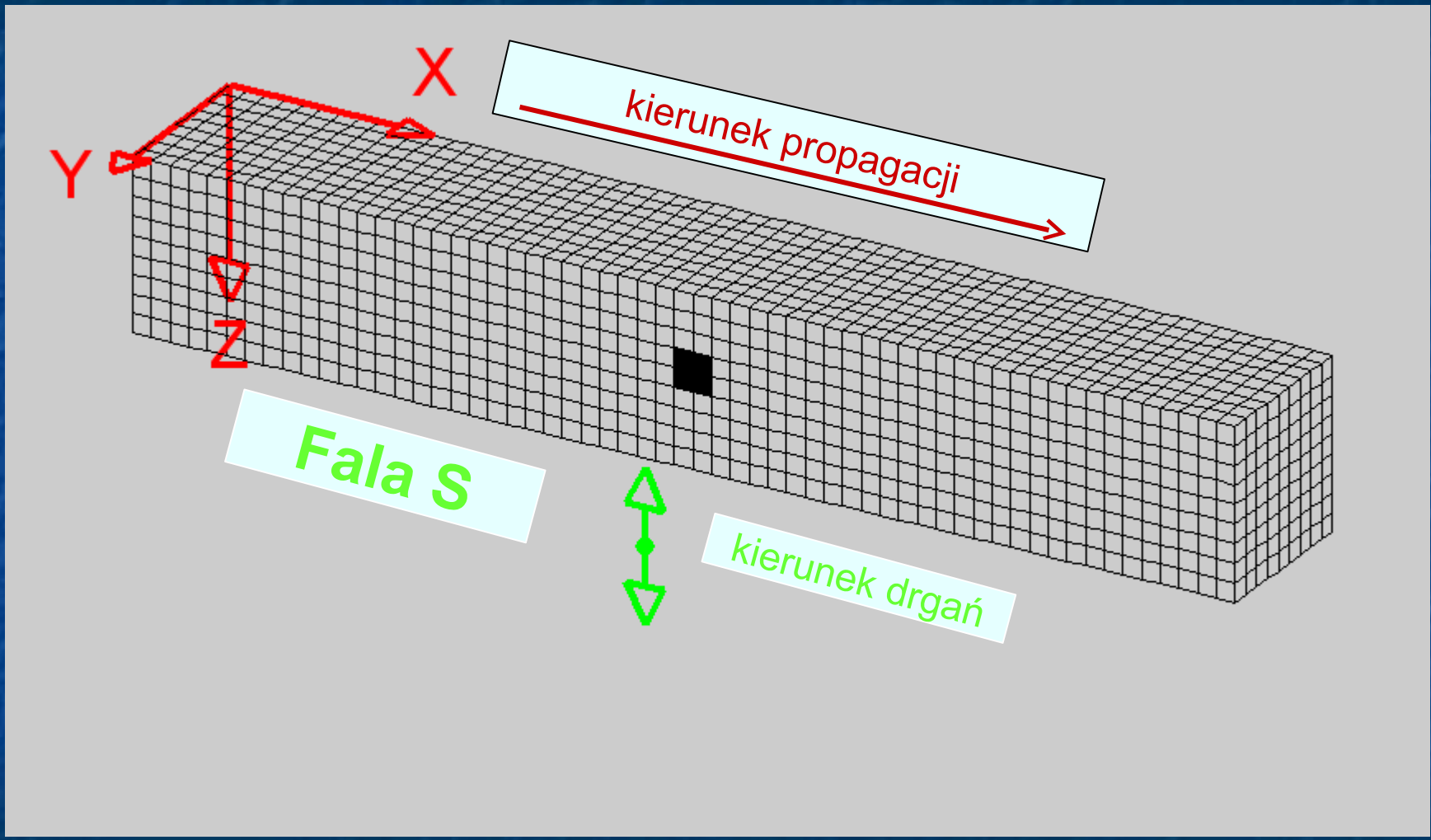


Epicentra ok. 29.000 trzęsień ziemi z lat 1961-1967

Fale sejsmiczne




X
Y
Z
kierunek propagacji
Fala P
kierunek drgań


X
Y
Z
kierunek propagacji
Fala S
kierunek drgań

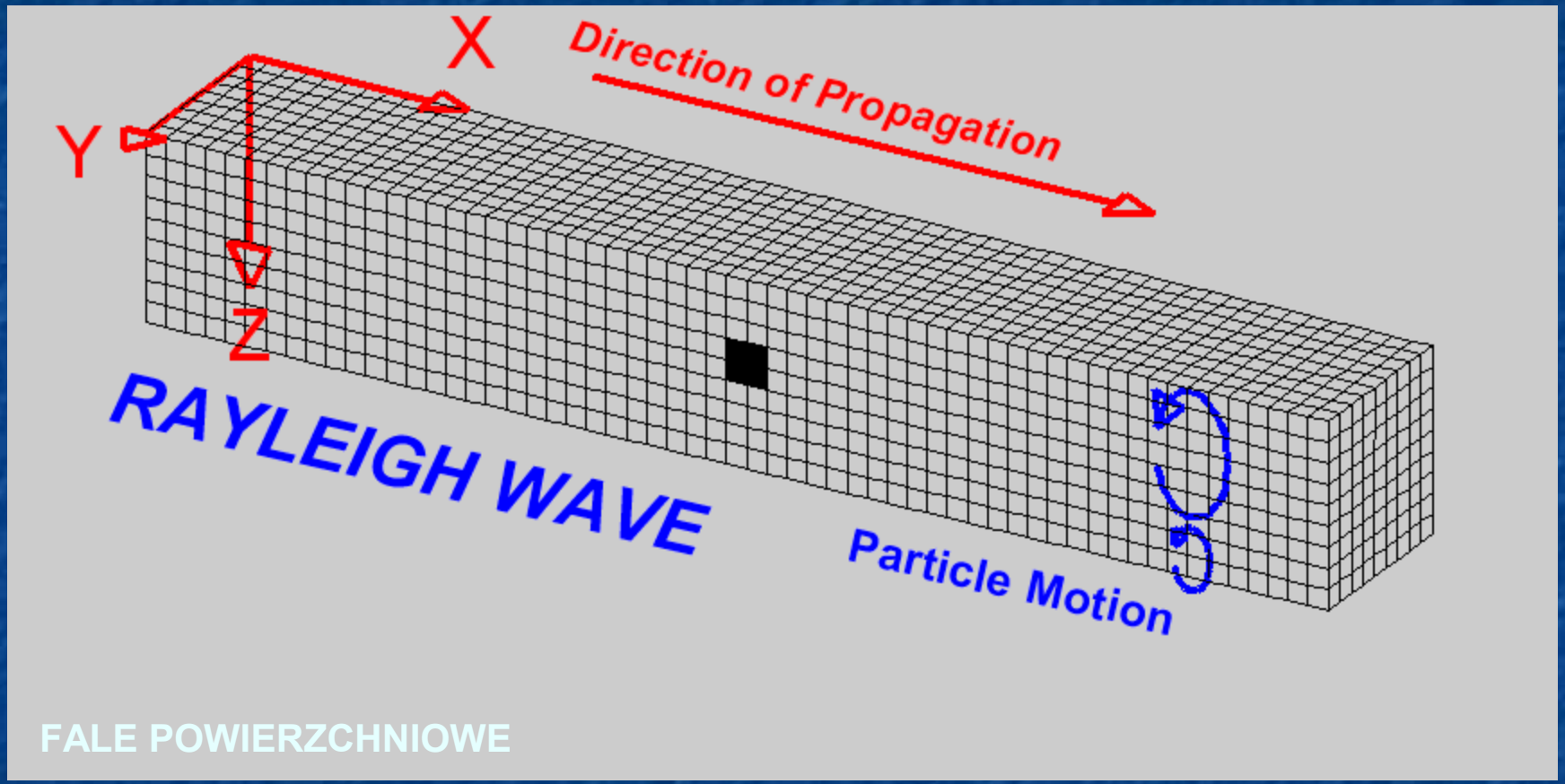
$$\mathbf{F} + (\lambda + \mu)\, \mathit{grad}\, \mathit{div}\, \mathbf{u} + \mu \Delta \mathbf{u} = \rho\, d^2\mathbf{u}/dt^2$$

fale P i S

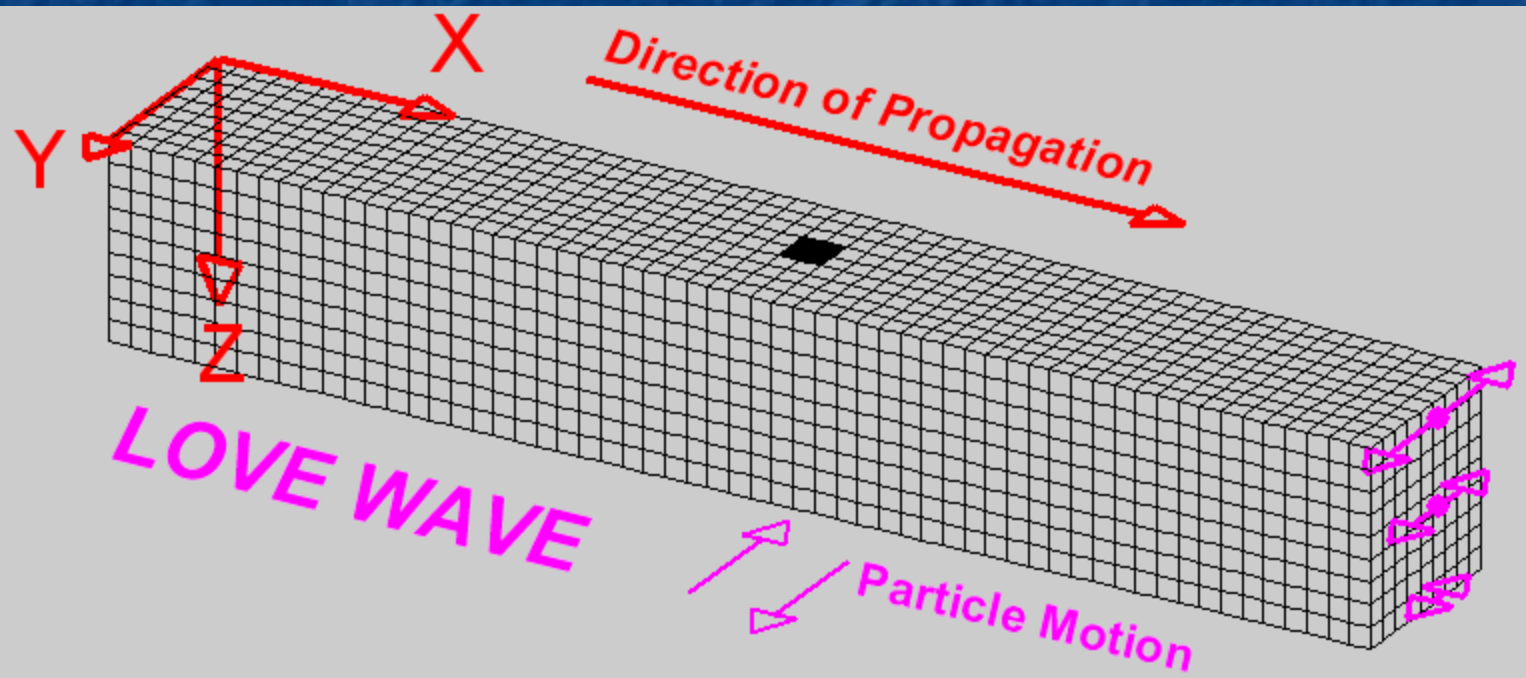
$$Vp = [(\lambda + 2\mu)/\rho]^{1/2}$$
$$Vs = [\mu/\rho]^{1/2}$$

dla skał $\lambda \approx \mu$, wtedy

$$Vp/Vs = [(\mu+2\mu)/\mu]^{1/2} = 3^{1/2} \approx 1.73...$$



FALE POWIERZCHNIOWE



FALE POWIERZCHNIOWE

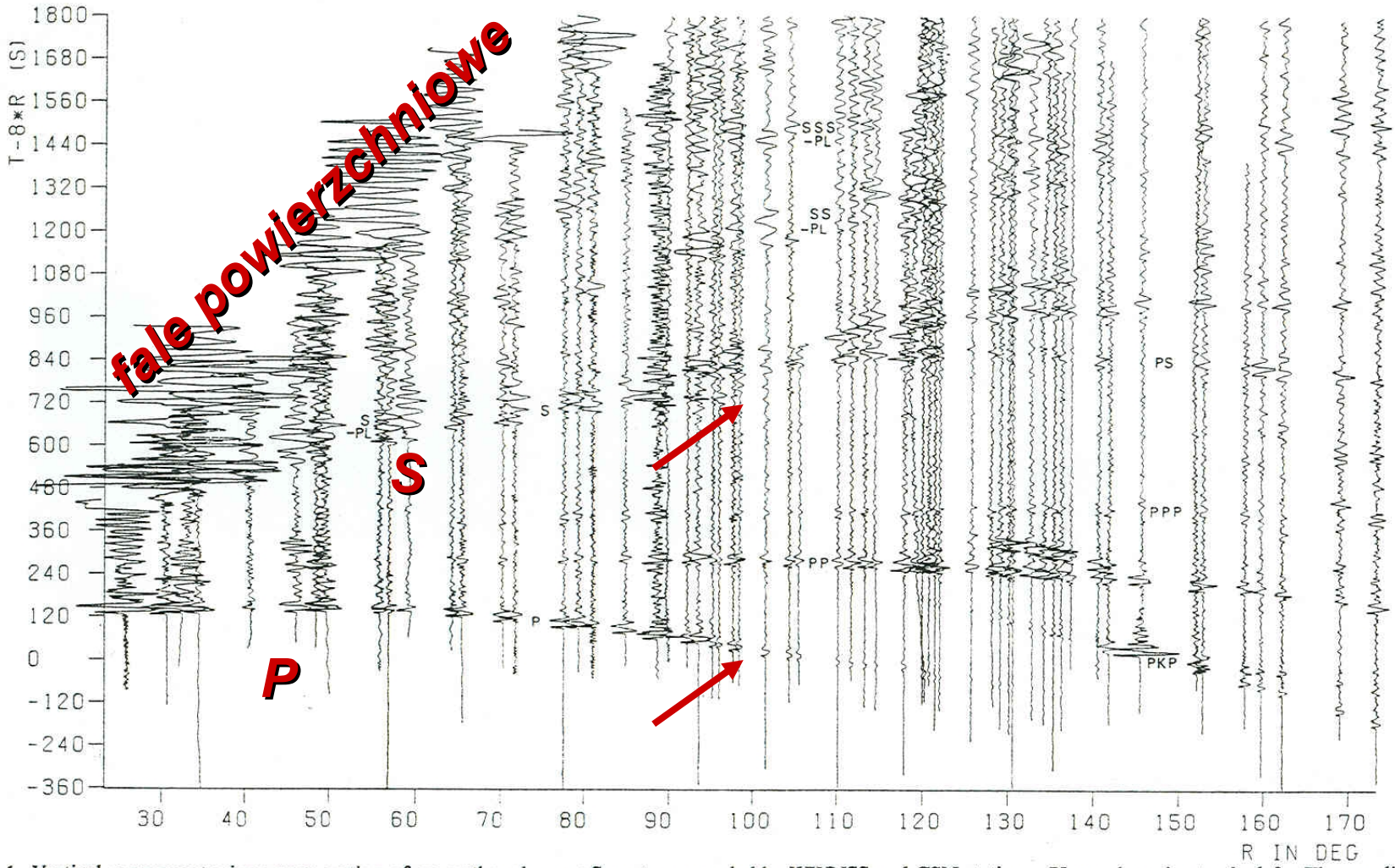


FIG. 1. Vertical component seismogram section of an earthquake near Sumatra, recorded by WWNSS and CSN stations. Upward motion to the left. The amplitude scales of all traces are the same. See text for more details.

fale objętościowe P i S, załamane, odbite, przemienne, fale powierzchniowe ...

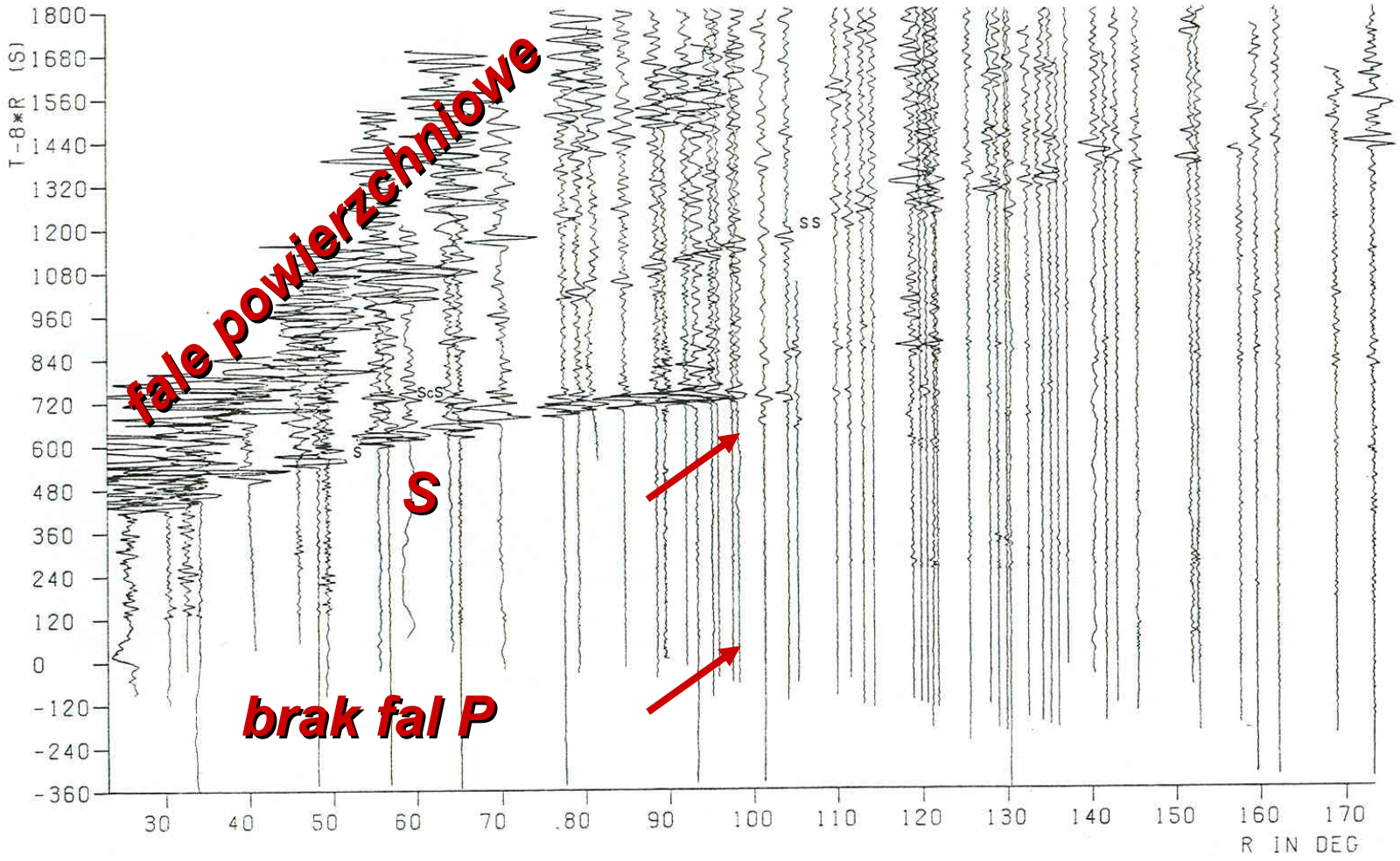
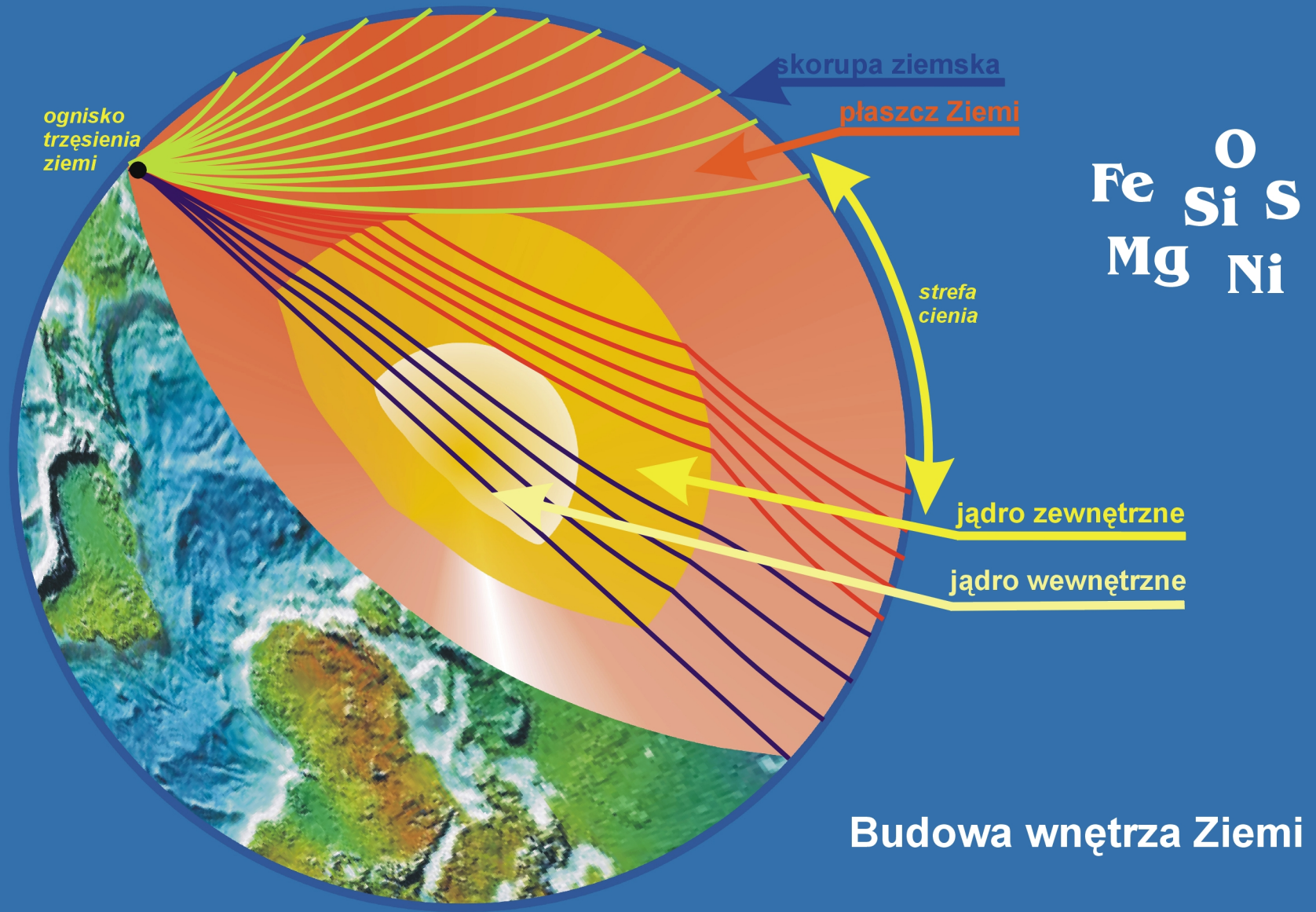
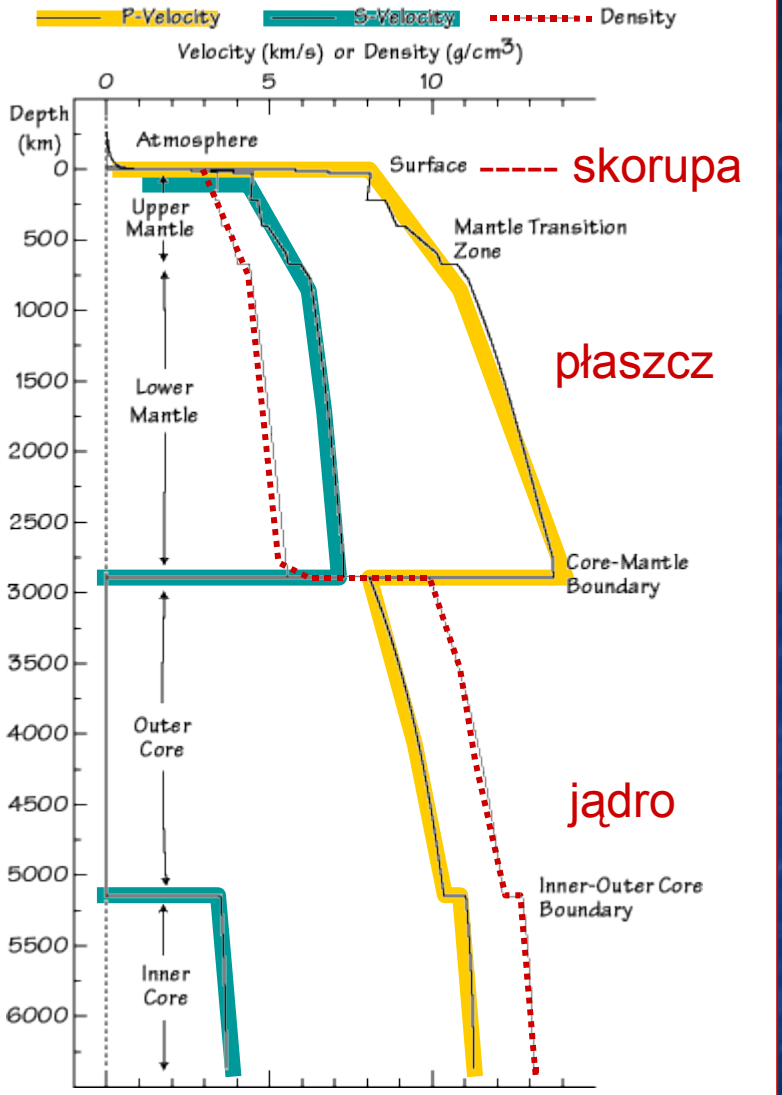


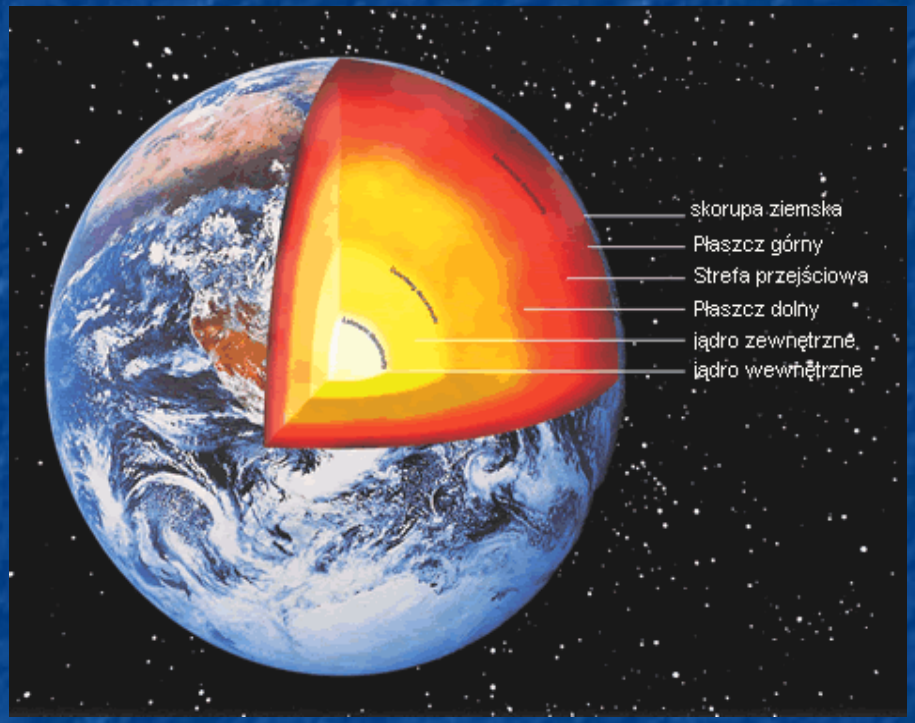
FIG. 3. Transverse component seismogram section of the same earthquake. Clockwise motion, relative to epicentre, to the right. Amplitude scale is the same



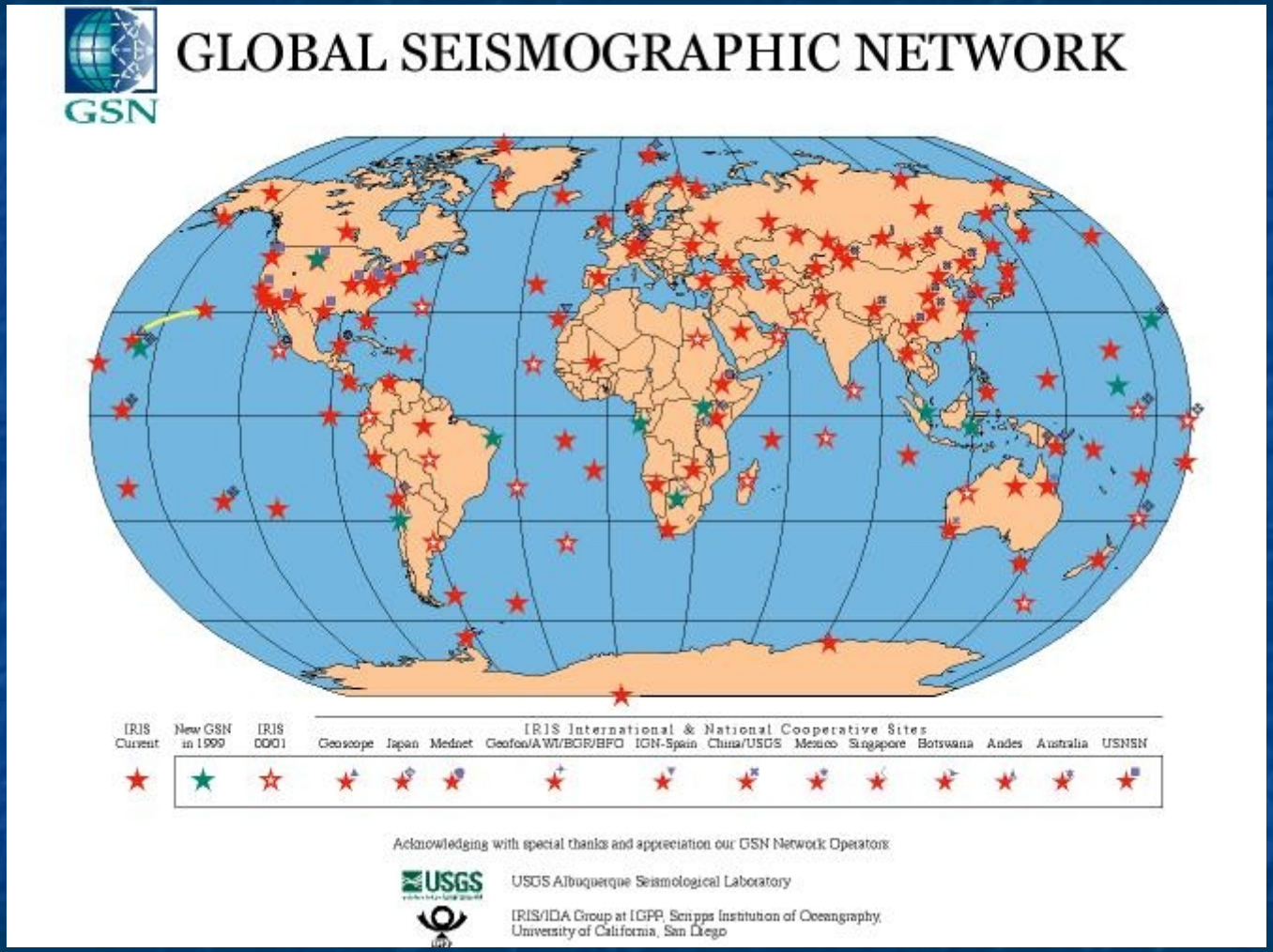
Budowa wnętrza Ziemi

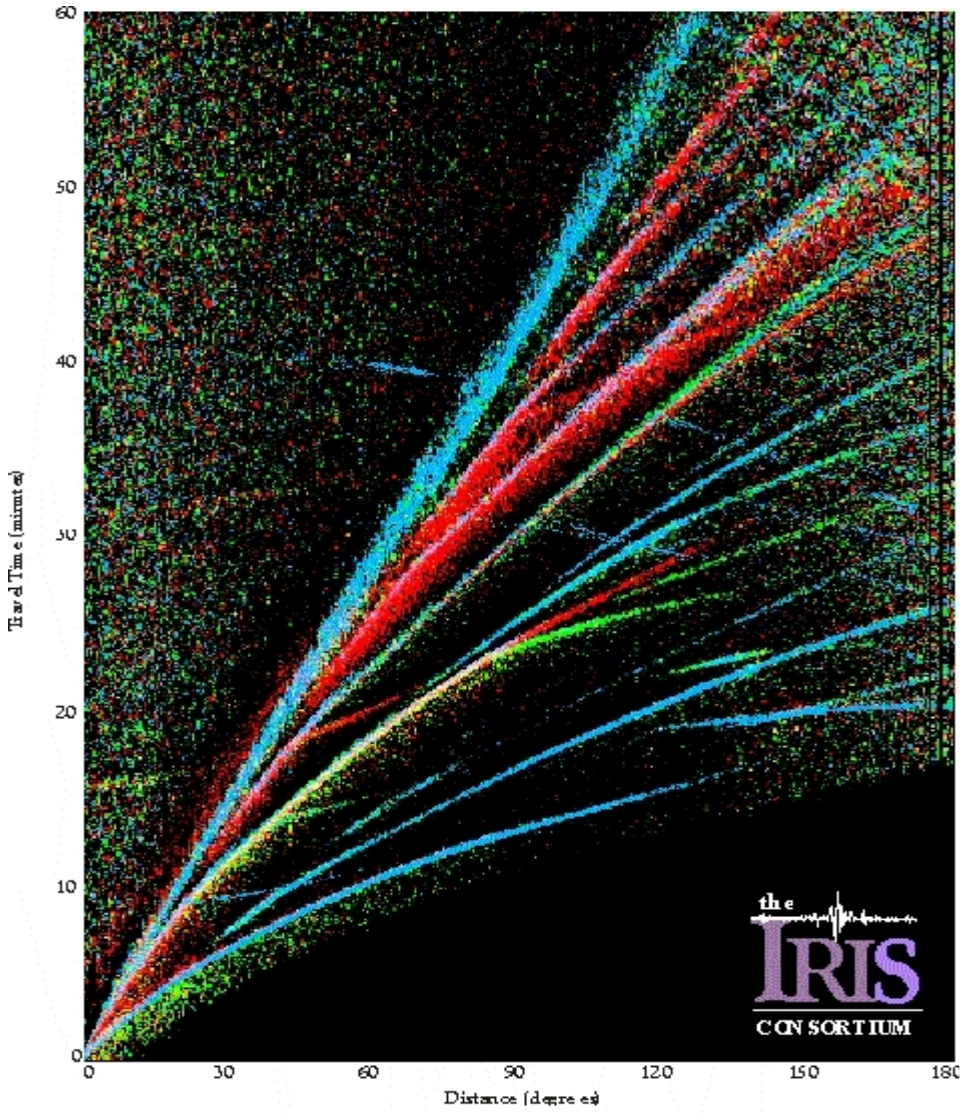
Budowa wnętrza Ziemi

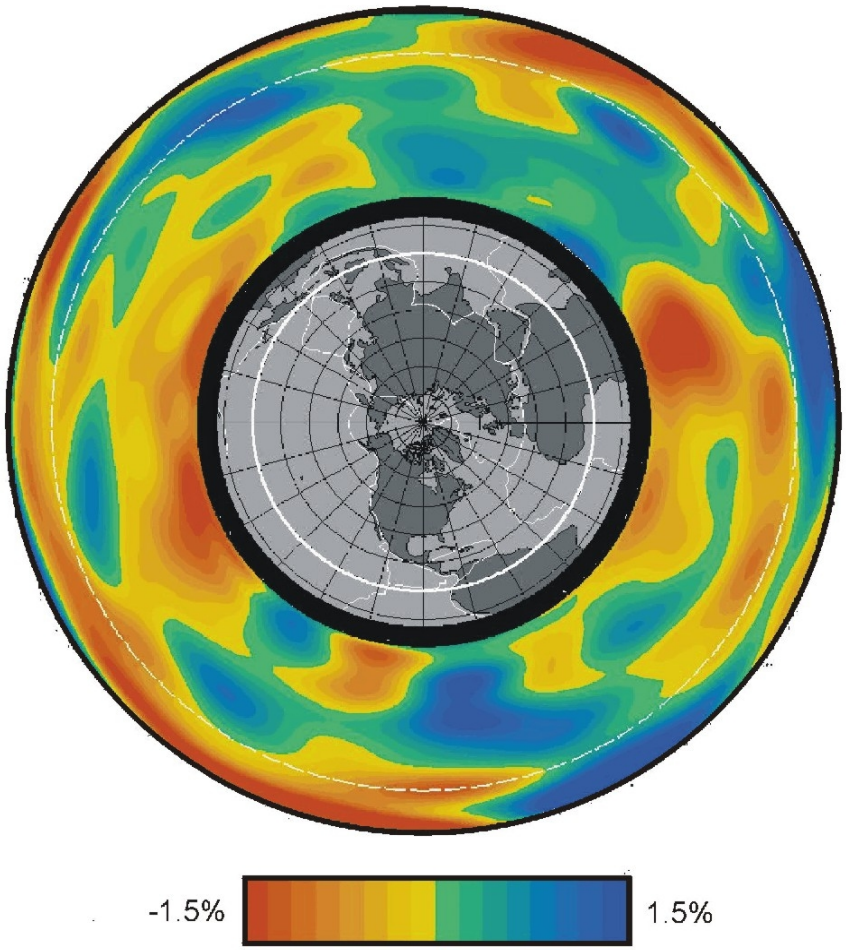




prędkość w km/s
gęstość w g/cm^3


GSN
GLOBAL SEISMOGRAPHIC NETWORK
IRIS Current
New GSN in 1999
IRIS 0001
IRIS International & National Cooperative Sites
Geoscope
Japan
Mednet
Geofon/AWI/BGR/BFO
IGN-Spain
China/USGS
Mexico
Singapore
Botswana
Andes
Australia
USNSN
Acknowledging with special thanks and appreciation our GSN Network Operators
USGS
USGS Albuquerque Seismological Laboratory
IRIS/IDA Group at IGPP, Scripps Institution of Oceanography, University of California, San Diego





Tomografia sejsmiczna - Hodografy i anomalie rozkładu prędkości fal P w płaszczu Ziemi - cięcie równikowe

Eksperymenty sejsmiczne i budowa skorupy ziemskiej




CT 18176



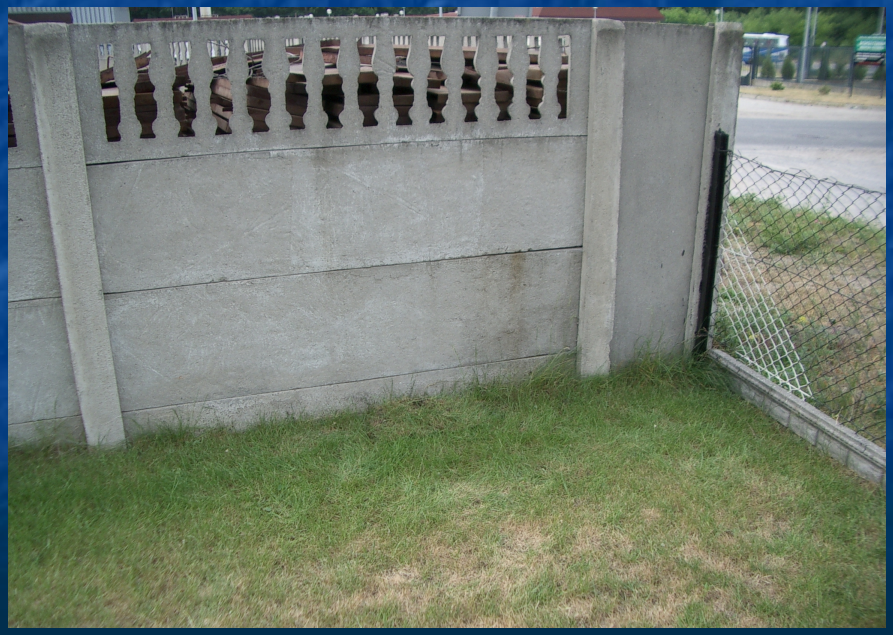












POLONAISE'97

POlish Lithospheric ONsets - An International Seismic Experiment
May 1997

Organizing Committee:

Aleksander Guterch, Institute of Geophysics, Polish Academy of Sciences, Poland
Marek Grad, Institute of Geophysics, University of Warsaw, Poland
Hans Thybo, University of Copenhagen, Denmark
G. Randy Keller, University of Texas at El Paso, USA

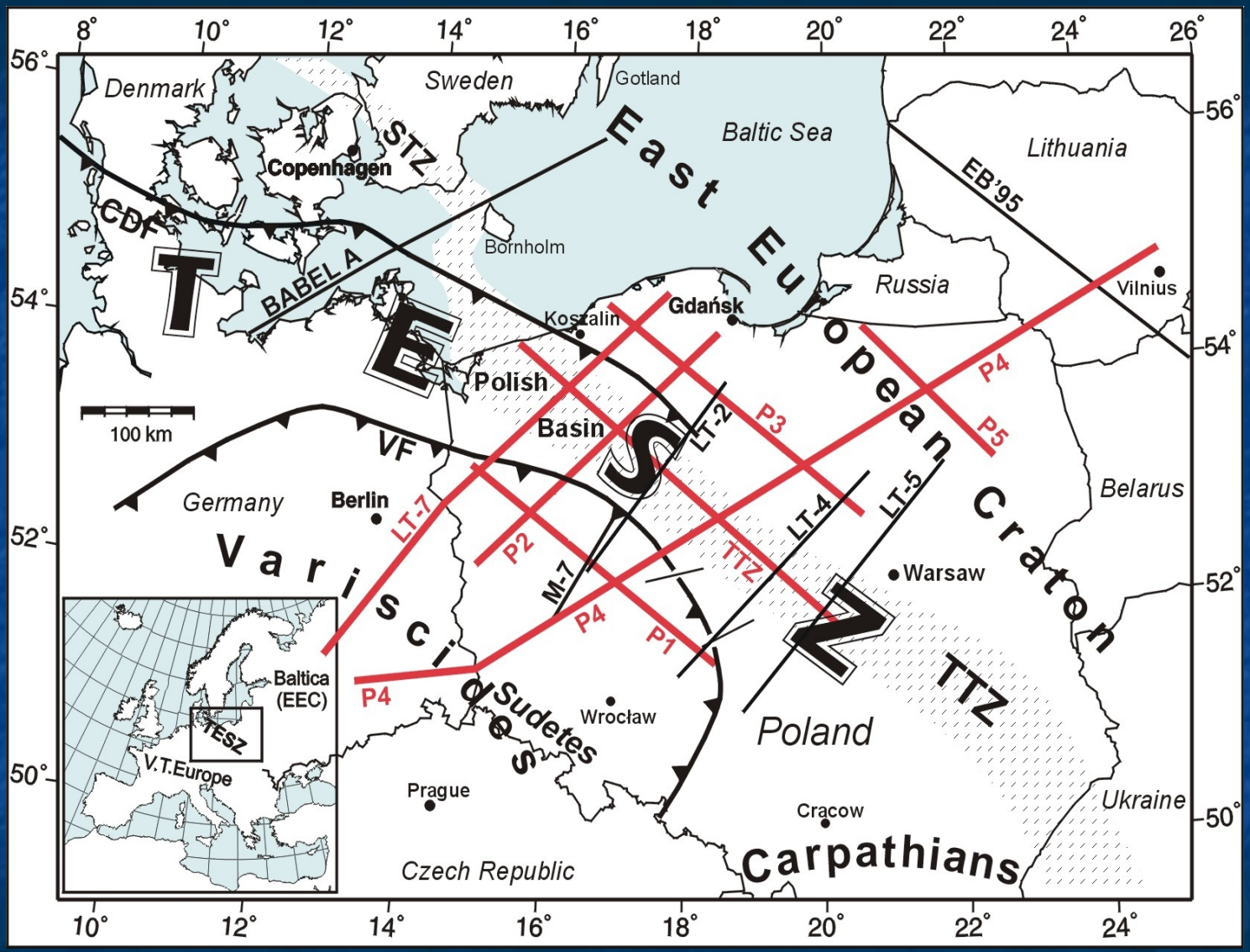


The POLONAISE Working Group:

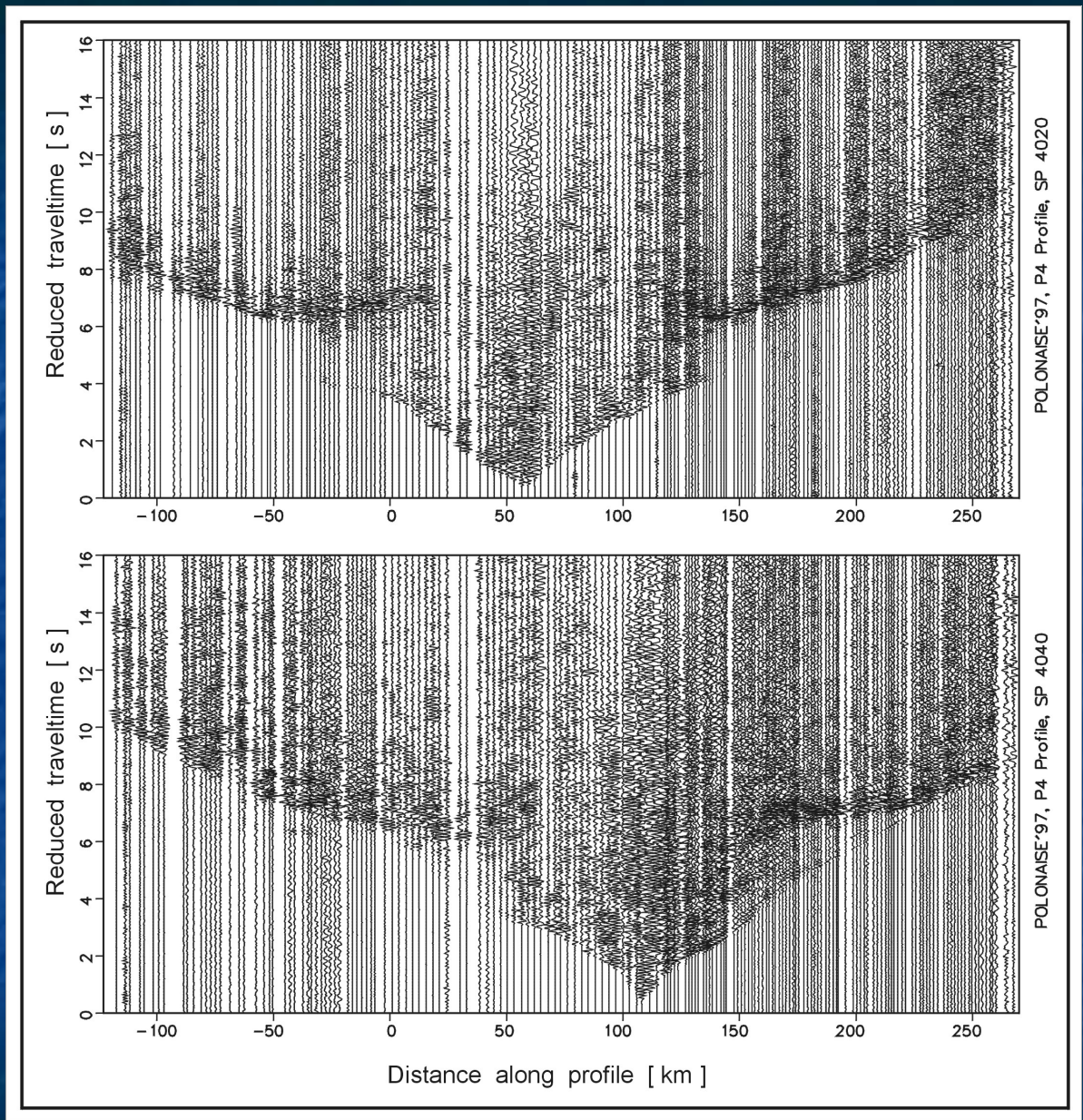
W. Czuba, E. Gaczyński, M. Grad, A. Guterch, T. Janik, R. Materzok, P. Środa, M. Wilde-Piórko, S.L. Jensen, H. Thybo, S. Harder, G.R. Keller, K.C. Miller, A. Schulze, K. Schuster, K. Komminaho, U. Luosto, T. Tiira, J. Yliniemi, G. Motuza, V. Nasedkin, C.-E. Lund



Eksperyment POLONAISE'97

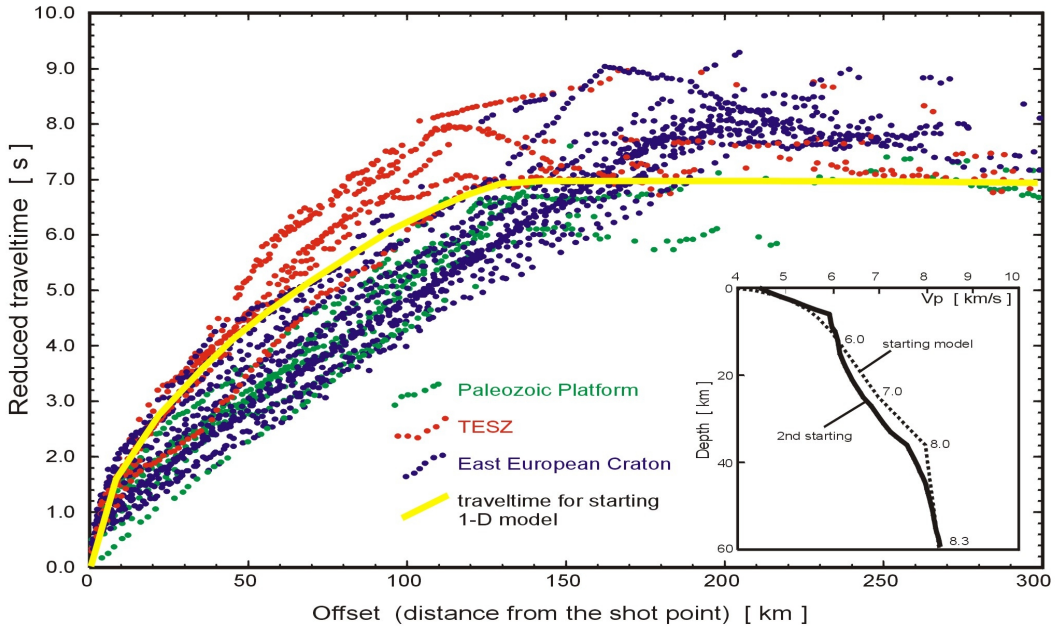


Eksperyment POLONAISE'97 profil P4

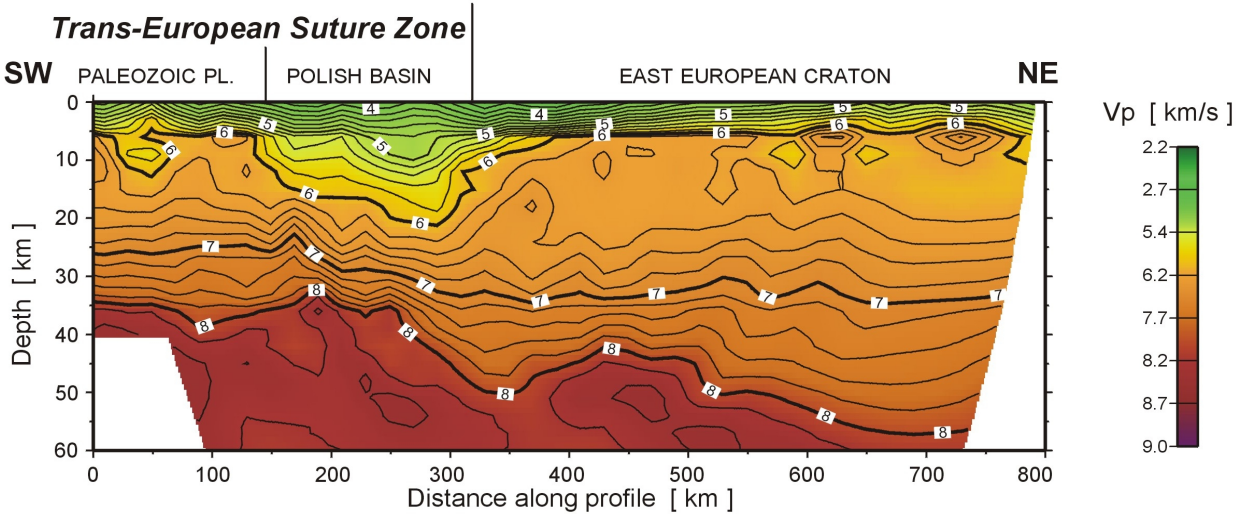


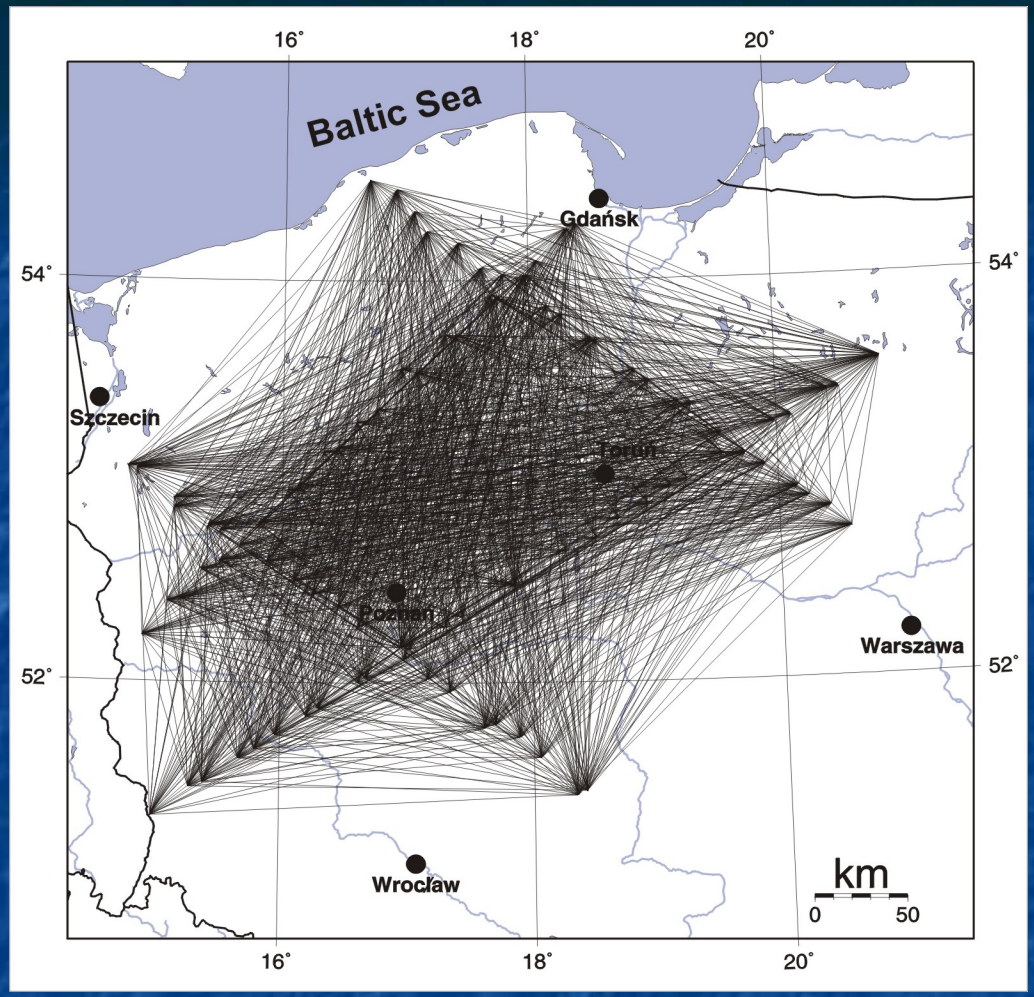
Eksperyment POLONAISE'97 profil P4

hodograf

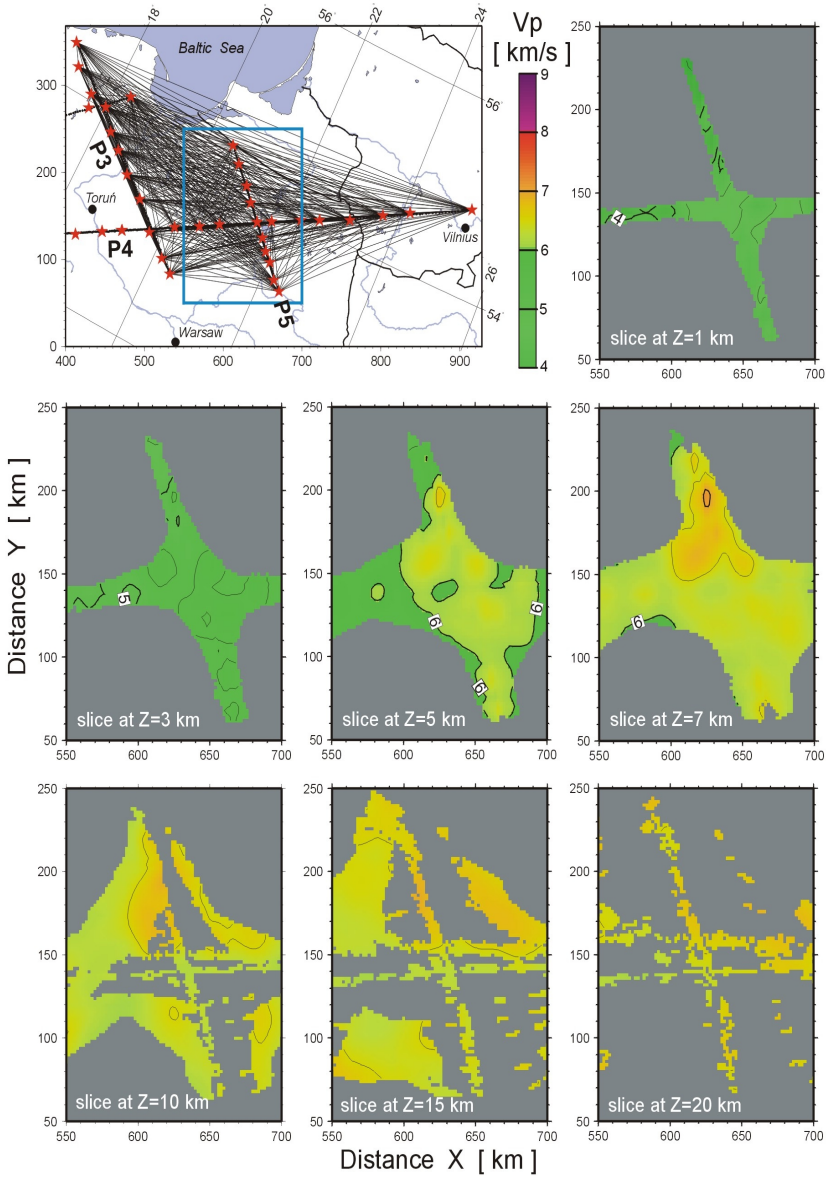


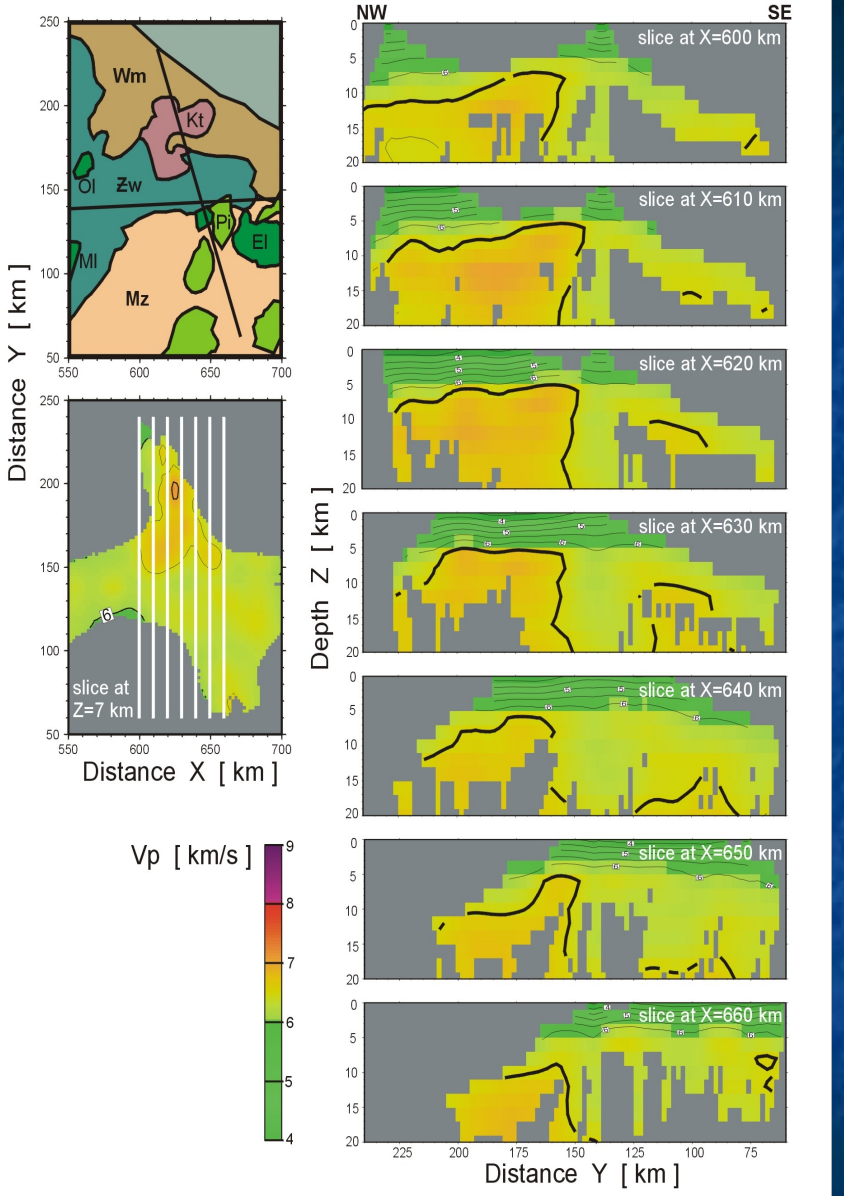
tomograficzny model 2-D



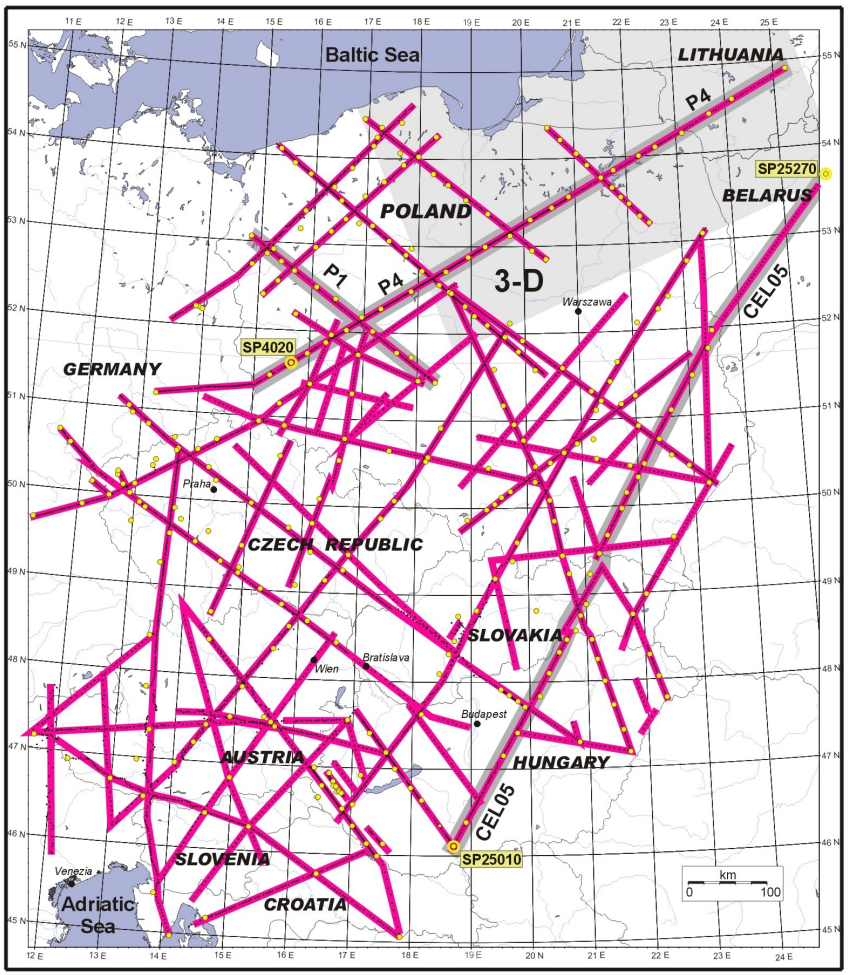


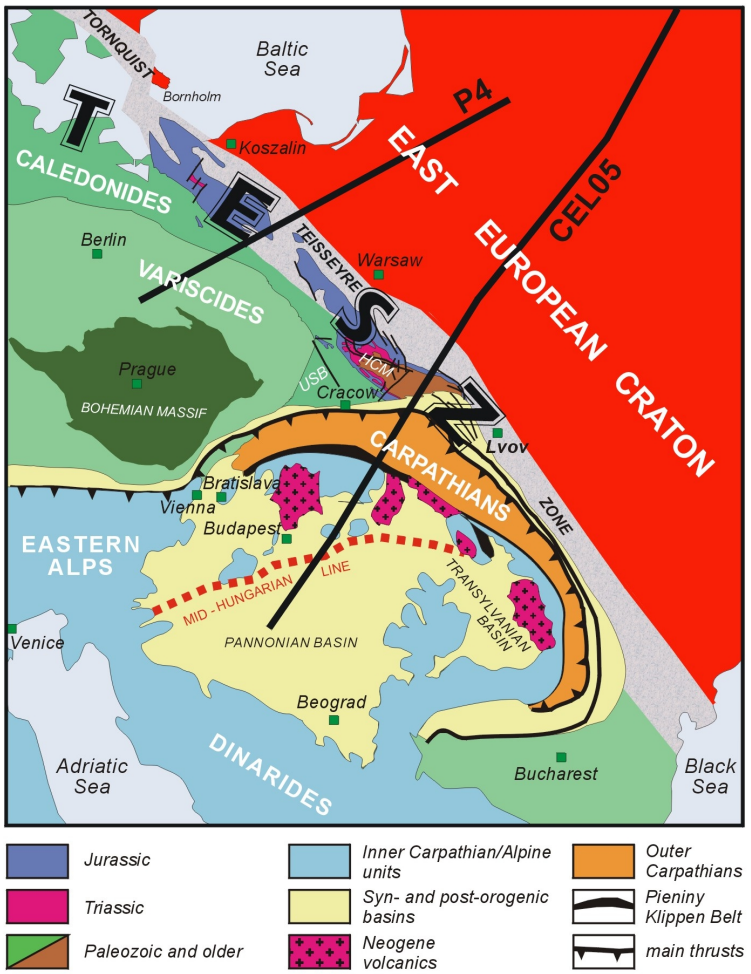
POLONAISE'97, rejestracje przestrzenne


Baltic Sea
Toruń
Warsaw
Vilnius
P3
P4
P5
Vp
[km/s]
slice at Z=1 km
slice at Z=3 km
slice at Z=5 km
slice at Z=7 km
slice at Z=10 km
slice at Z=15 km
slice at Z=20 km
Distance Y [km]
Distance X [km]


Wm
Kt
Ol
Zw
Pl
El
Ml
Mz
slice at Z=7 km
Distance Y [km]
Distance X [km]
Vp [km/s]
NW
SE
slice at X=600 km
slice at X=610 km
slice at X=620 km
slice at X=630 km
slice at X=640 km
slice at X=650 km
slice at X=660 km
Depth Z [km]
Distance Y [km]

Wielkie eksperymenty sejsmiczne w Europie Centralnej 1997-2003





CELEBRATION 2000

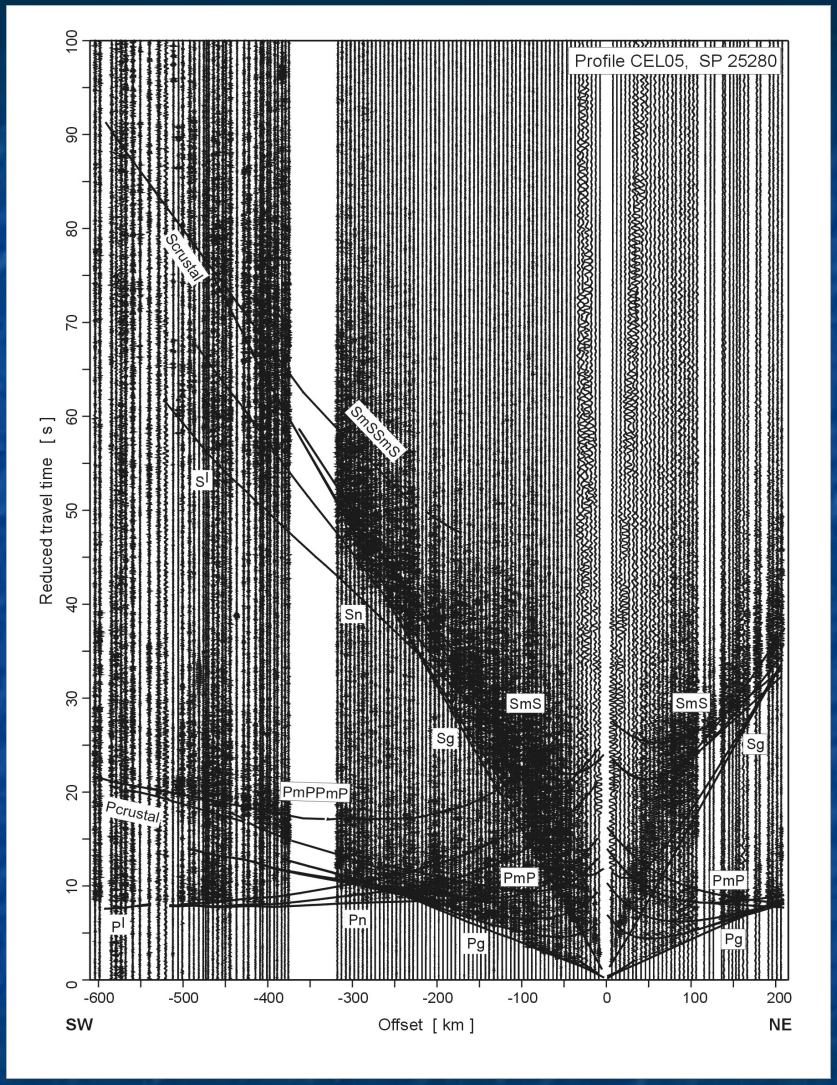


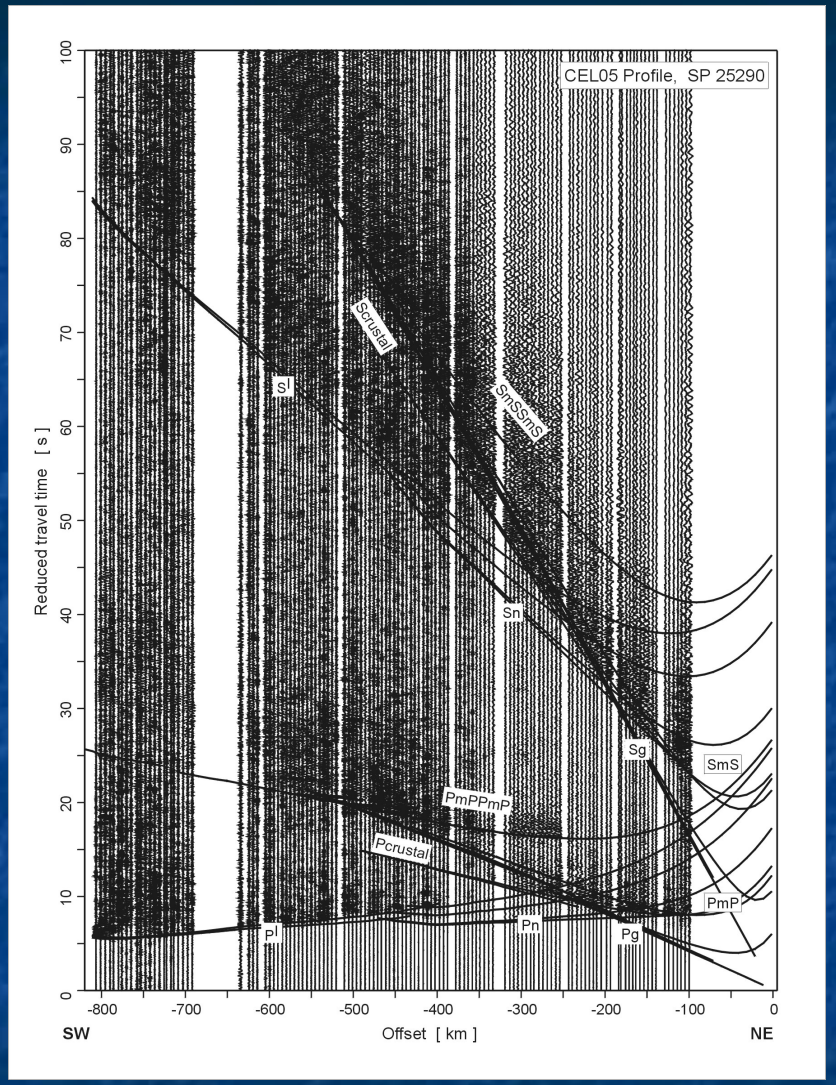
Central European Lithospheric Experiment Based on Refraction, June 2000

Organizing Committee:

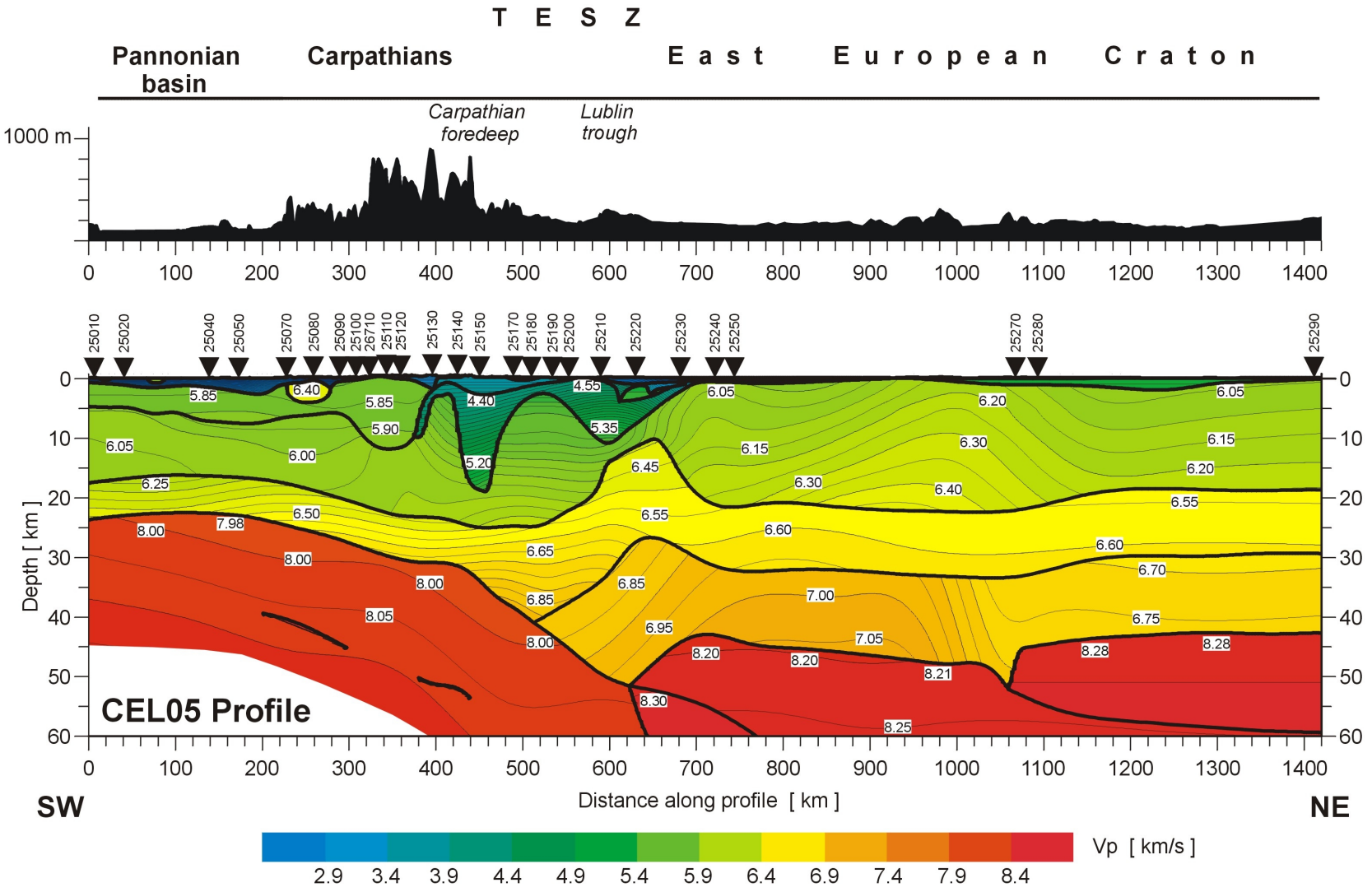
Aleksander Guterch, Institute of Geophysics, Polish Academy of Sciences, Poland
Marek Grad, Institute of Geophysics, University of Warsaw, Poland
G. Randy Keller, University of Texas at El Paso, USA
Karoly Posgay, Eotvos Lorand Geophysical Institute, Budapest, Hungary
Josef Vozar, Geological Survey, Bratislava, Slovak Republic
Ales Spicak, Geophysical Institute, Prague, Czech Republic
Ewald Brueckl, Technical University, Vienna, Austria
Zoltan Hajnal, University of Saskatchewan, Canada
Hans Thybo, University of Copenhagen, Denmark
Oguz Selvi, TUBITAK-MAM, Earth Science Research Institute, Gebze, Turkey

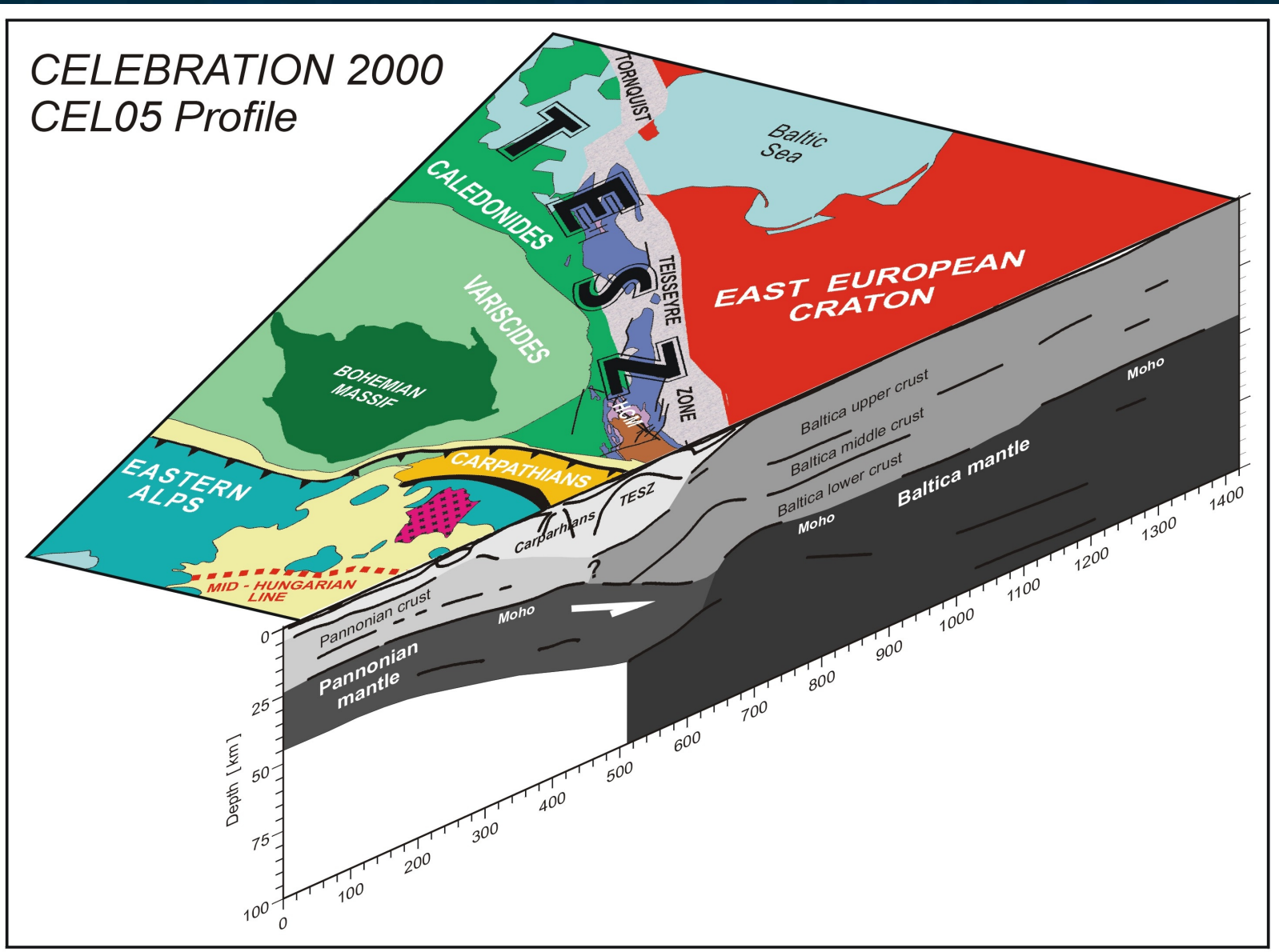
Experiment and Interpretation Team: *Wojciech Czuba, Edward Gaczyński, Tomasz Janik, Michał Malinowski, Piotr Środa, Monika Wilde-Piórko,* Poland; *Tiffni Bond, Steven Harder, Kate C. Miller,* USA; *Tamas Fancsik, Endre Hegedus, Attila C. Kovacs,* Hungary; *Pavala Hrubcova,* Czech Republic; *Kai Aric, Franz Kohlbeck, Michael Behm, Werner Chwatal,* Austria; *Isa Asudeh, Ronald Clowes,* Canada; *Peer Joergensen,* Denmark; *Sergey L. Kostiuchenko,* Russia; *Gerhard Jentzsch, Dieter Kracke,* Germany; *Timo Tiira, Jukka Yliniemi, Kari Komminaho,* Finland; *Andrey A. Belinsky,* Belarus


Profile CEL05, SP 25280
Reduced travel time [s]
Offset [km]
SW
NE
Scrustal
Sl
SnSSnS
Sn
SmS
Sg
PmPPmP
Pcrustal
PmP
Pl
Pn
Pg

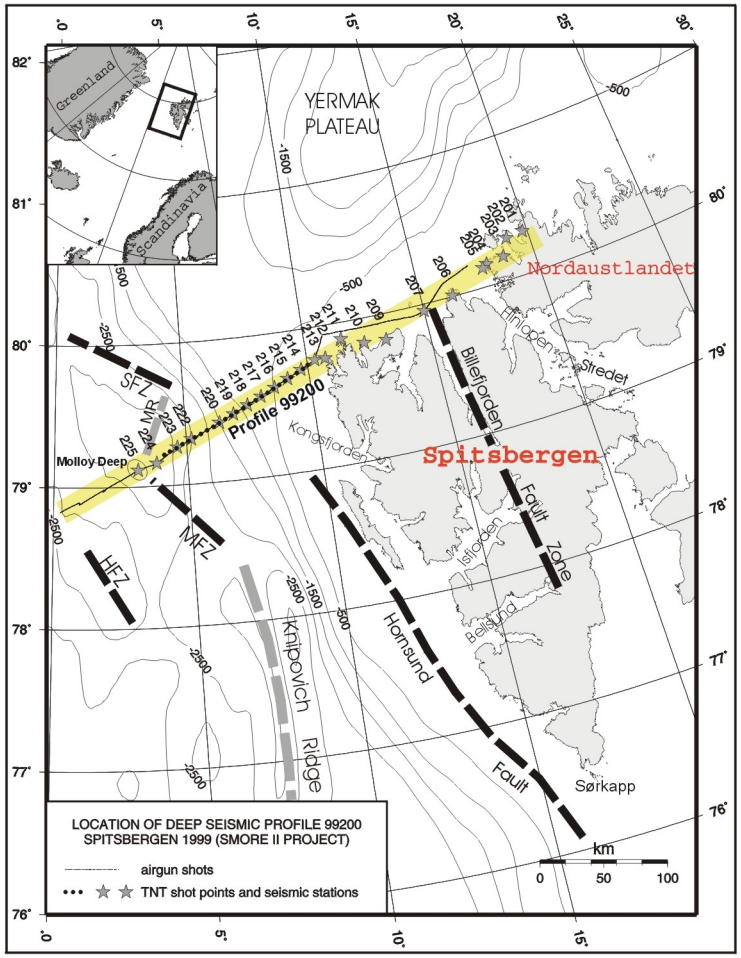

CEL05 Profile, SP 25290
Reduced travel time [s]
Offset [km]
SW
NE
Scrustal
Sl
SnSSmS
Sn
Sg
SmS
PmPPmP
Pcrustal
PmP
Pl
Pn
Pg

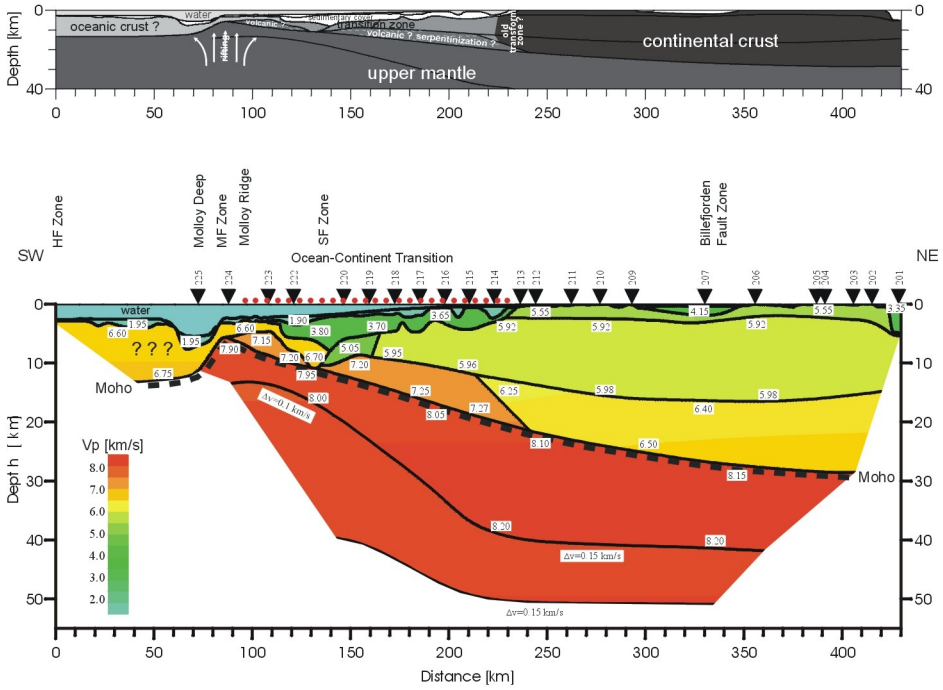
Struktura skorupy ziemskiej na profilu CEL05, CELEBRATION 2000




CELEBRATION 2000
CEL05 Profile
TORNQUIST
Baltic Sea
CALEDONIDES
TESZ
TEISSEYRE
ZONE
EAST EUROPEAN CRATON
VARISCIDES
BOHEMIAN MASSIF
EASTERN ALPS
CARPATHIANS
MID - HUNGARIAN LINE
Carpathians
TESZ
Baltica upper crust
Baltica middle crust
Baltica lower crust
Moho
Baltica mantle
Pannonian crust
Moho
Pannonian mantle
Depth [km]
0
25
50
75
100
0
100
200
300
400
500
600
700
800
900
1000
1100
1200
1300
1400

Spitsbergen 99200 Profile



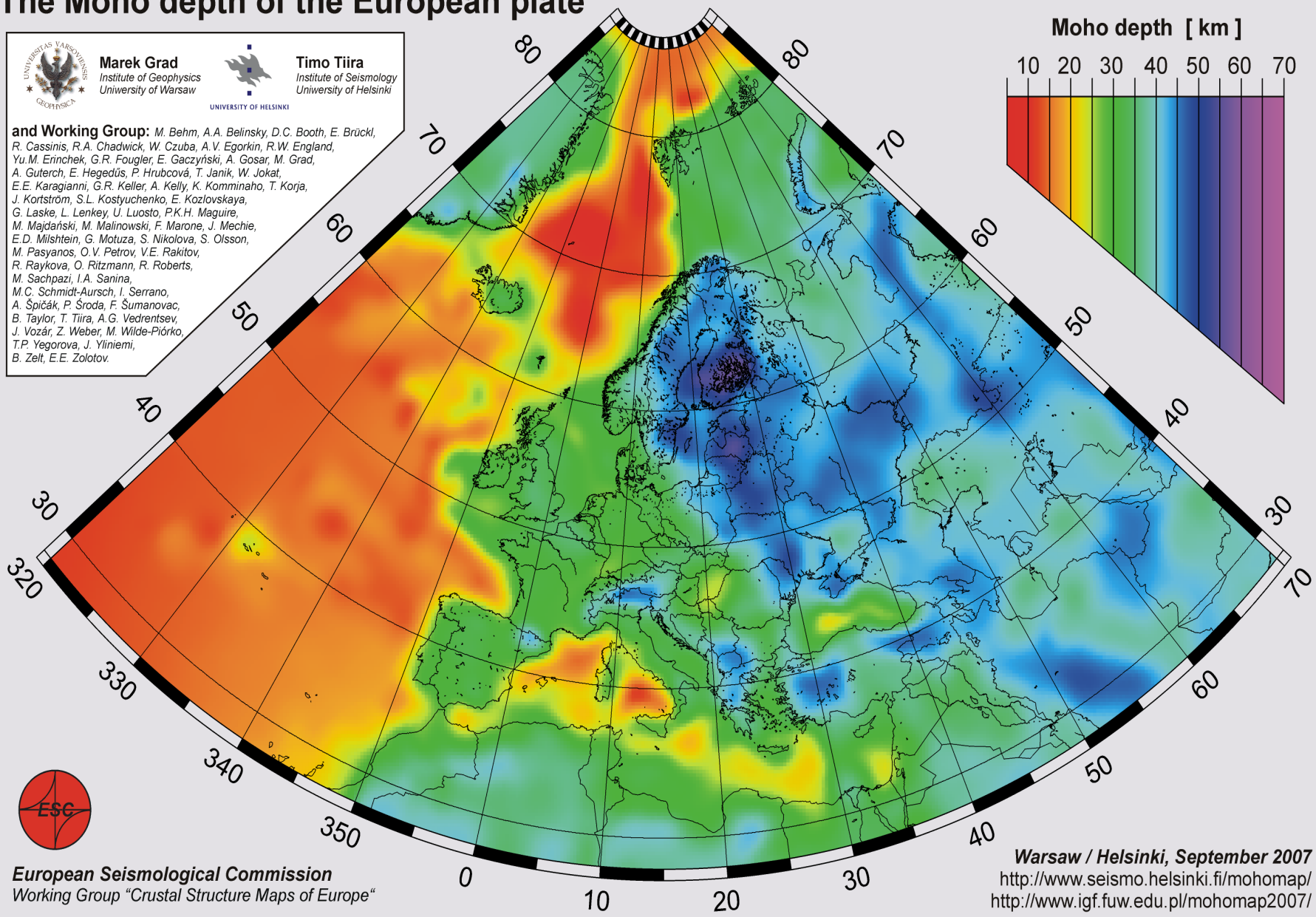


The Moho depth of the European plate

Marek Grad
Institute of Geophysics
Uniwersity of Warsaw

Timo Tiira
Institute of Seismology
Uniwersity of Helsinki

and Working Group: *M. Behm, A.A. Belinsky, D.C. Booth, E. Brückl, R. Cassinis, R.A. Chadwick, W. Czuba, A.V. Egorkin, R.W. England, Yu.M. Erinchek, G.R. Fougler, E. Gaczyński, A. Gosar, M. Grad, A. Guterch, E. Hegedűs, P. Hrubcová, T. Janik, W. Jokat, E.E. Karagianni, G.R. Keller, A. Kelly, K. Komminaho, T. Korja, J. Kortström, S.L. Kostyuchenko, E. Kozlovskaya, G. Laske, L. Lenkey, U. Luosto, P.K.H. Maguire, M. Majdański, M. Malinowski, F. Marone, J. Mechie, E.D. Milshtein, G. Motuza, S. Nikolova, S. Olsson, M. Pasyanos, O.V. Petrov, V.E. Rakitov, R. Raykova, O. Ritzmann, R. Roberts, M. Sachpazi, I.A. Sanina, M.C. Schmidt-Aursch, I. Serrano, A. Špičák, P. Środa, F. Šumanovac, B. Taylor, T. Tiira, A.G. Vedrentsev, J. Vozár, Z. Weber, M. Wilde-Piórko, T.P. Yegorova, J. Yliniemi, B. Zelt, E.E. Zolotov.*



European Seismological Commission
Working Group "Crustal Structure Maps of Europe"

Warsaw / Helsinki, September 2007
http://www.seismo.helsinki.fi/mohomap/
http://www.igf.fuw.edu.pl/mohomap2007/

The Moho depth of the European plate

Marek Grad
Institute of Geophysics
Uniwersity of Warsaw

Timo Tiira
Institute of Seismology
Uniwersity of Helsinki

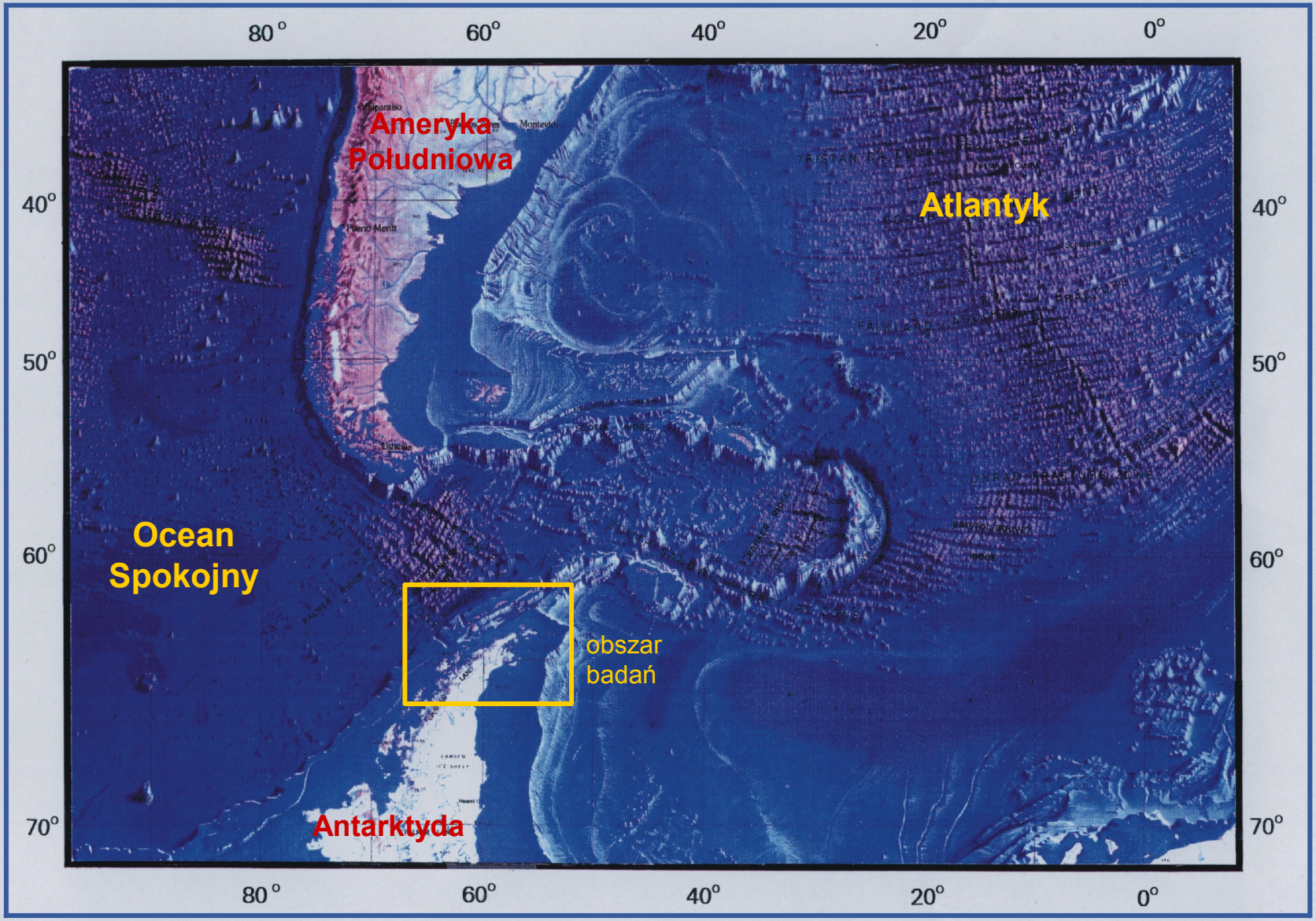
and Working Group: *M. Behm, A.A. Belinsky, D.C. Booth, E. Brückl, R. Cassinis, R.A. Chadwick, W. Czuba, A.V. Egorkin, R.W. England, Yu.M. Erinchek, G.R. Fougler, E. Gaczyński, A. Gosar, M. Grad, A. Guterch, E. Hegedűs, P. Hrubcová, T. Janik, W. Jokat, E.E. Karagianni, G.R. Keller, A. Kelly, K. Komminaho, T. Korja, J. Kortström, S.L. Kostyuchenko, E. Kozlovskaya, G. Laske, L. Lenkey, U. Luosto, P.K.H. Maguire, M. Majdański, M. Malinowski, F. Marone, J. Mechie, E.D. Milshtein, G. Motuza, S. Nikolova, S. Olsson, M. Pasyanos, O.V. Petrov, V.E. Rakitov, R. Raykova, O. Ritzmann, R. Roberts, M. Sachpazi, I.A. Sanina, M.C. Schmidt-Aursch, I. Serrano, A. Špičák, P. Środa, F. Šumanovac, B. Taylor, T. Tiira, A.G. Vedrentsev, J. Vozár, Z. Weber, M. Wilde-Piórko, T.P. Yegorova, J. Yliniemi, B. Zelt, E.E. Zolotov.*

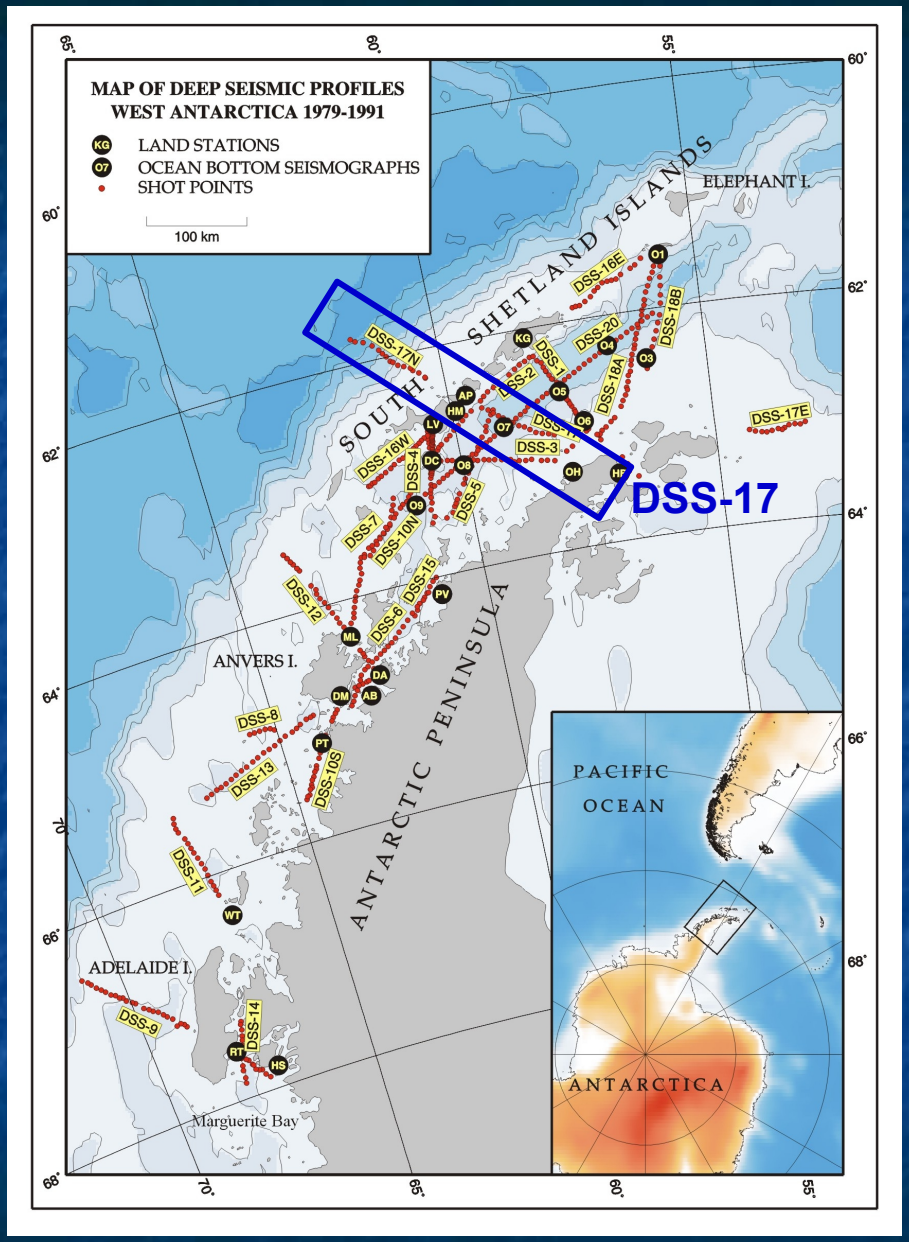
Moho depth [km]

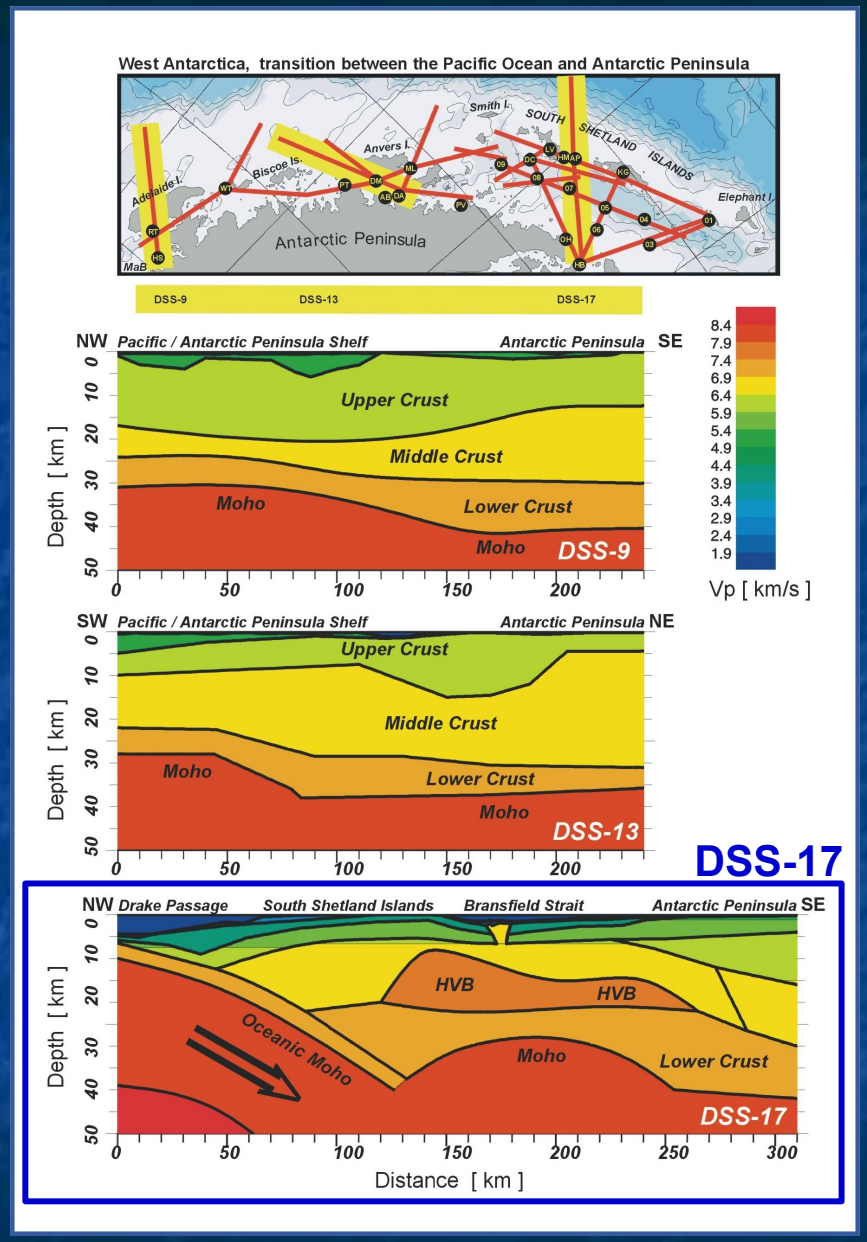
10 20 30 40 50 60 70

European Seismological Commission
Working Group "Crustal Structure Maps of Europe"

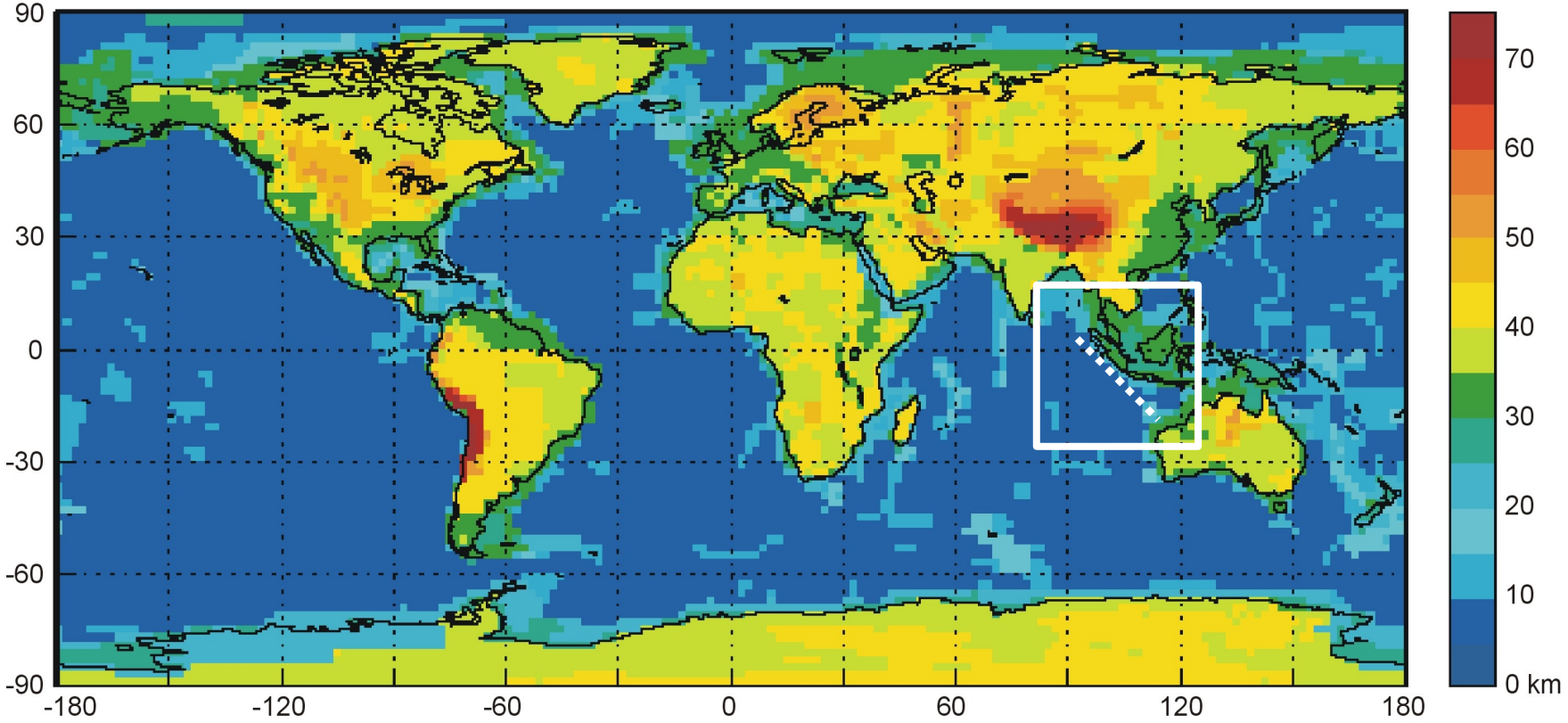
Warsaw / Helsinki, September 2007
http://www.seismo.helsinki.fi/mohomap/
http://www.igf.fuw.edu.pl/mohomap2007/


80°
60°
40°
20°
0°
40°
50°
60°
70°
Ameryka Południowa
Atlantyk
Ocean Spokojny
Antarktyda
obszar badań


MAP OF DEEP SEISMIC PROFILES
WEST ANTARCTICA 1979-1991
LAND STATIONS
OCEAN BOTTOM SEISMOGRAPHS
SHOT POINTS
100 km
SHETLAND ISLANDS
ELEPHANT I.
SOUTH
ANTARCTIC PENINSULA
ANVERS I.
ADELAIDE I.
Marguerite Bay
PACIFIC
OCEAN
ANTARCTICA
DSS-17
DSS-17N
DSS-16E
DSS-18B
DSS-20
DSS-18A
DSS-17E
DSS-16W
DSS-3
DSS-7
DSS-10N
DSS-12
DSS-15
DSS-6
DSS-8
DSS-13
DSS-10S
DSS-11
DSS-14
DSS-9


West Antarctica, transition between the Pacific Ocean and Antarctic Peninsula
Smith I.
SOUTH SHETLAND ISLANDS
Anvers I.
Biscoe Is.
Adelaide I.
Antarctic Peninsula
Elephant I.
MaB
DSS-9
DSS-13
DSS-17
NW Pacific / Antarctic Peninsula Shelf
Antarctic Peninsula SE
Upper Crust
Middle Crust
Lower Crust
Moho
DSS-9
Depth [km]
Vp [km/s]
8.4
7.9
7.4
6.9
6.4
5.9
5.4
4.9
4.4
3.9
3.4
2.9
2.4
1.9
SW Pacific / Antarctic Peninsula Shelf
Antarctic Peninsula NE
DSS-13
DSS-17
NW Drake Passage
South Shetland Islands
Bransfield Strait
Antarctic Peninsula SE
HVB
Oceanic Moho
Distance [km]

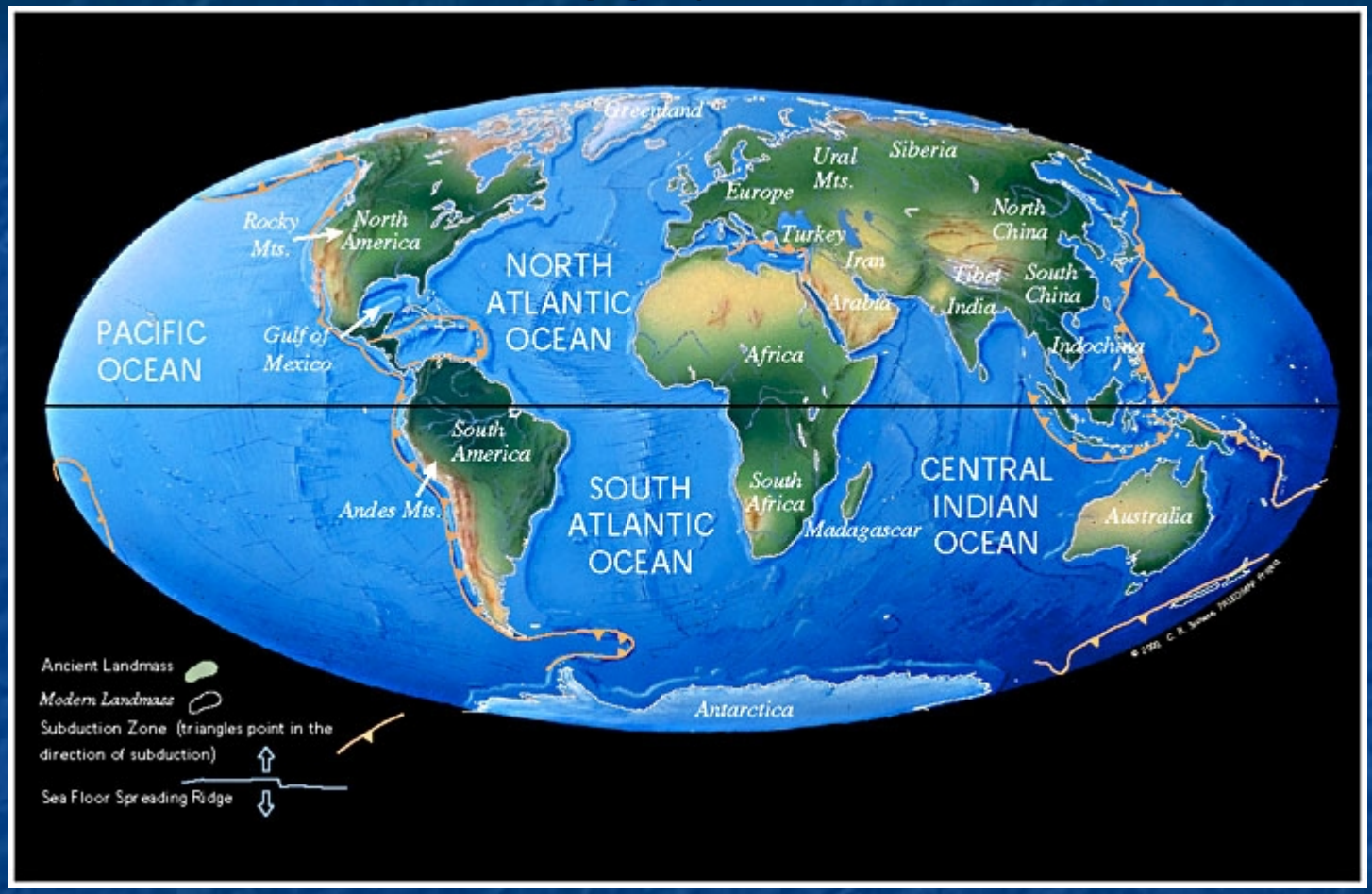
Grubość skorupy ziemskiej [w km]



(2°x2°; Laske, 2002; Mooney i in. 1998)

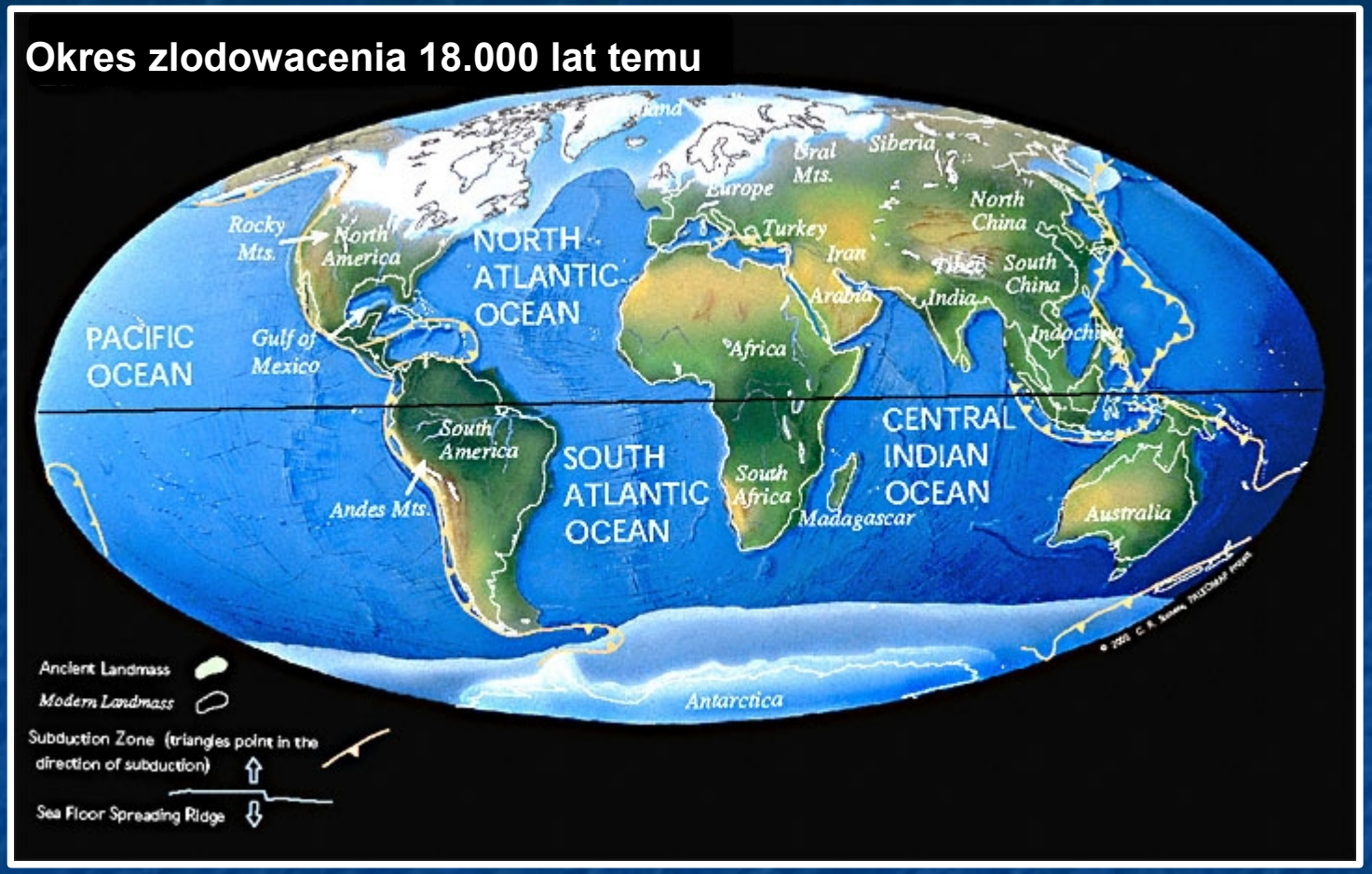
Czy kontynenty rzeczywiście mogą się przemieszczać?

Tak współcześnie wygląda Ziemia ...

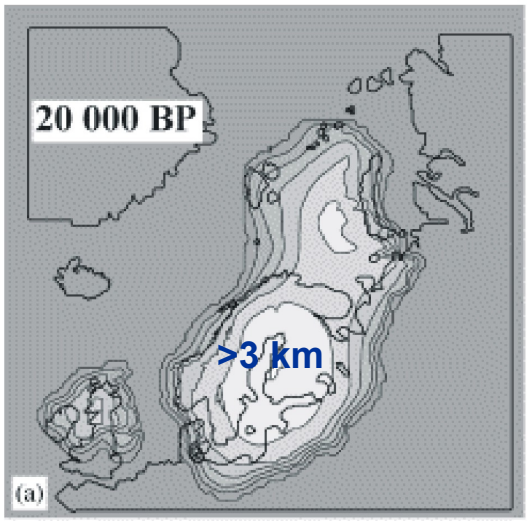


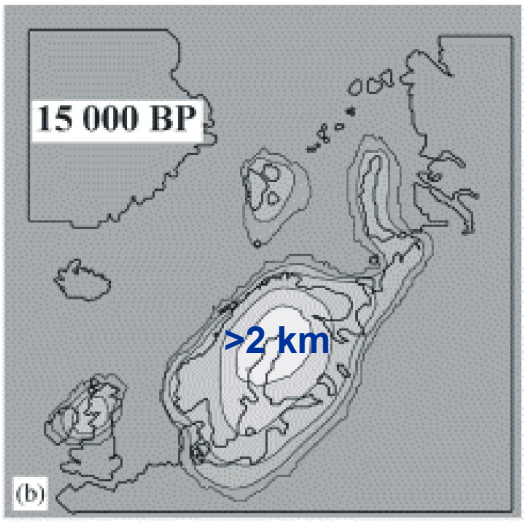
ale cofnijmy się o 18 tysięcy lat

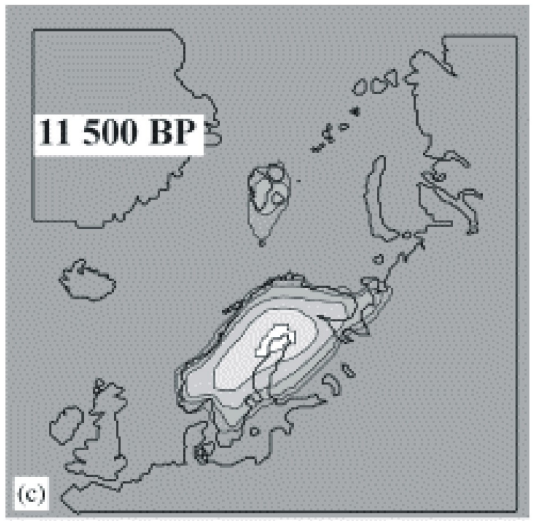
Okres zlodowacenia 18.000 lat temu

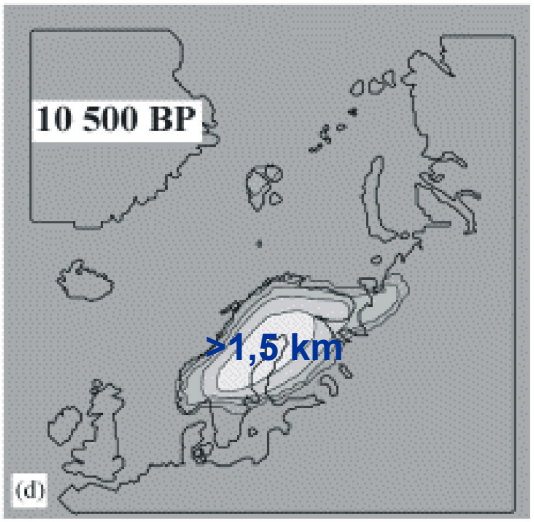


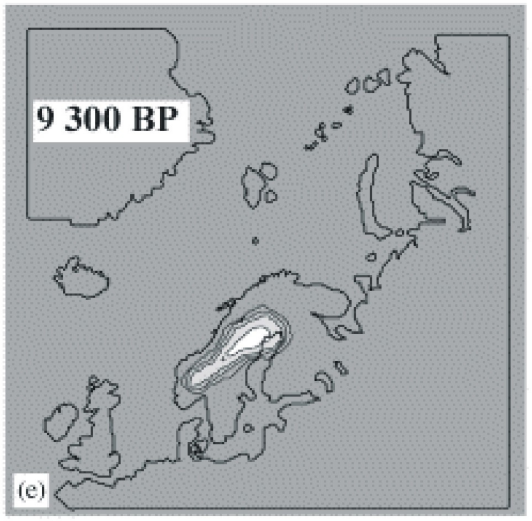
Zasięg lądolodu Skandynawskiego







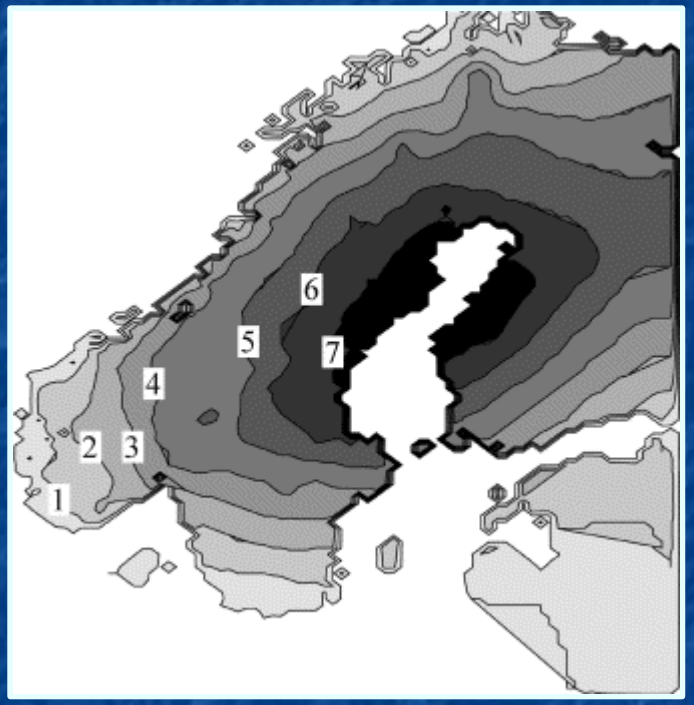




(a-d) izolinie co 500 m

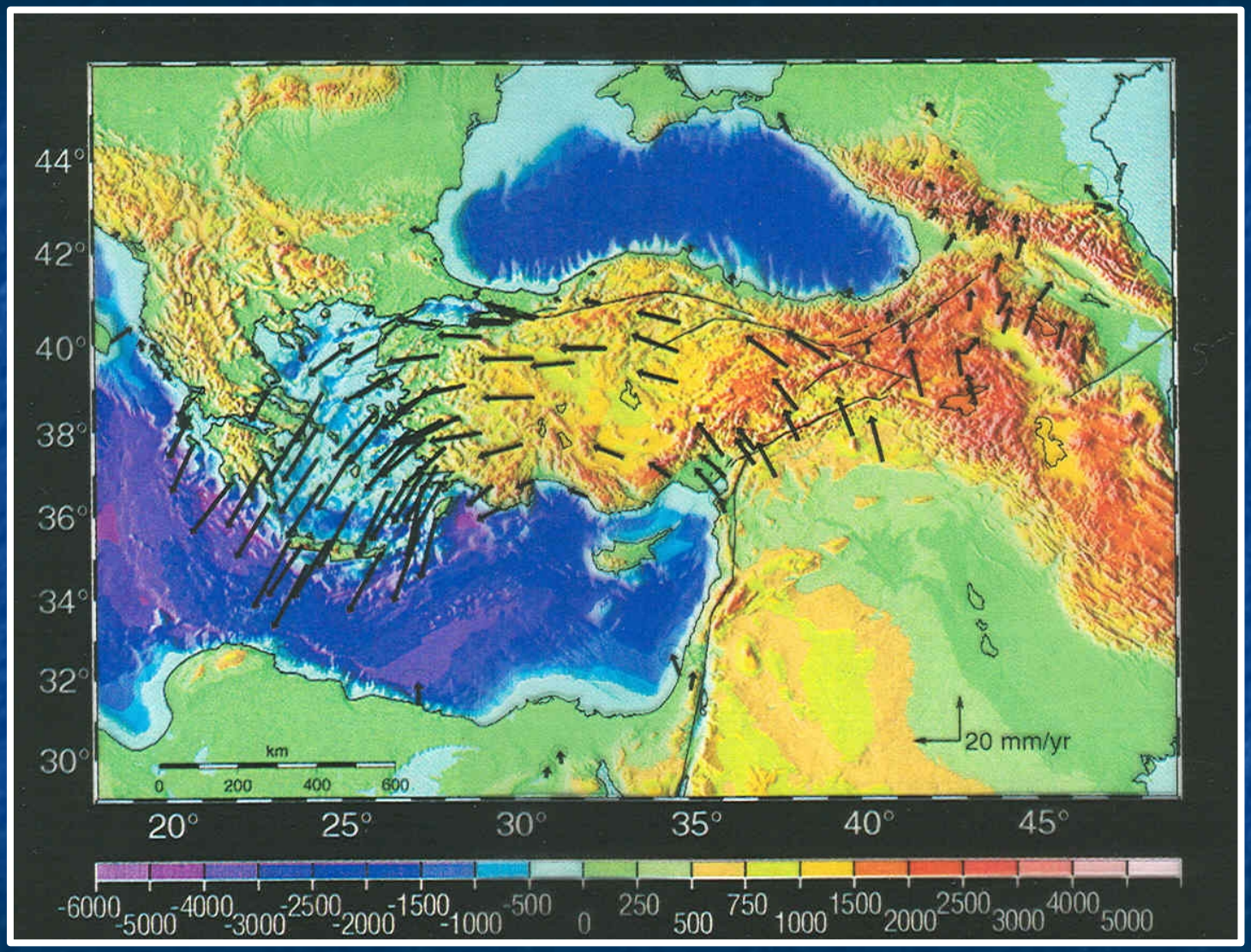
(e) izolinie co 200 m

Współczesne ruchy pionowe litosfery
wynurzanie Skandynawii



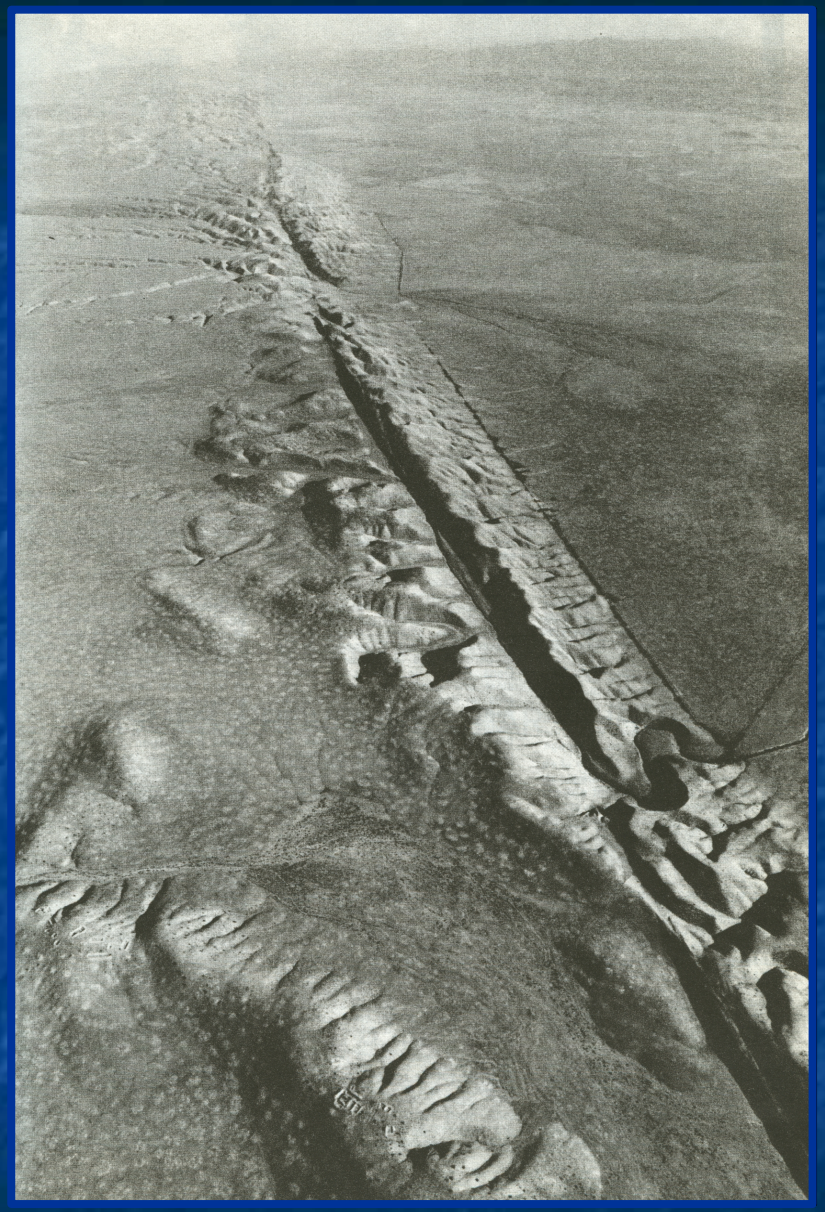
prędkość wynurzania w mm/rok

GPS – względne przemieszczenie wzdłuż uskoku Północnej Anatolii



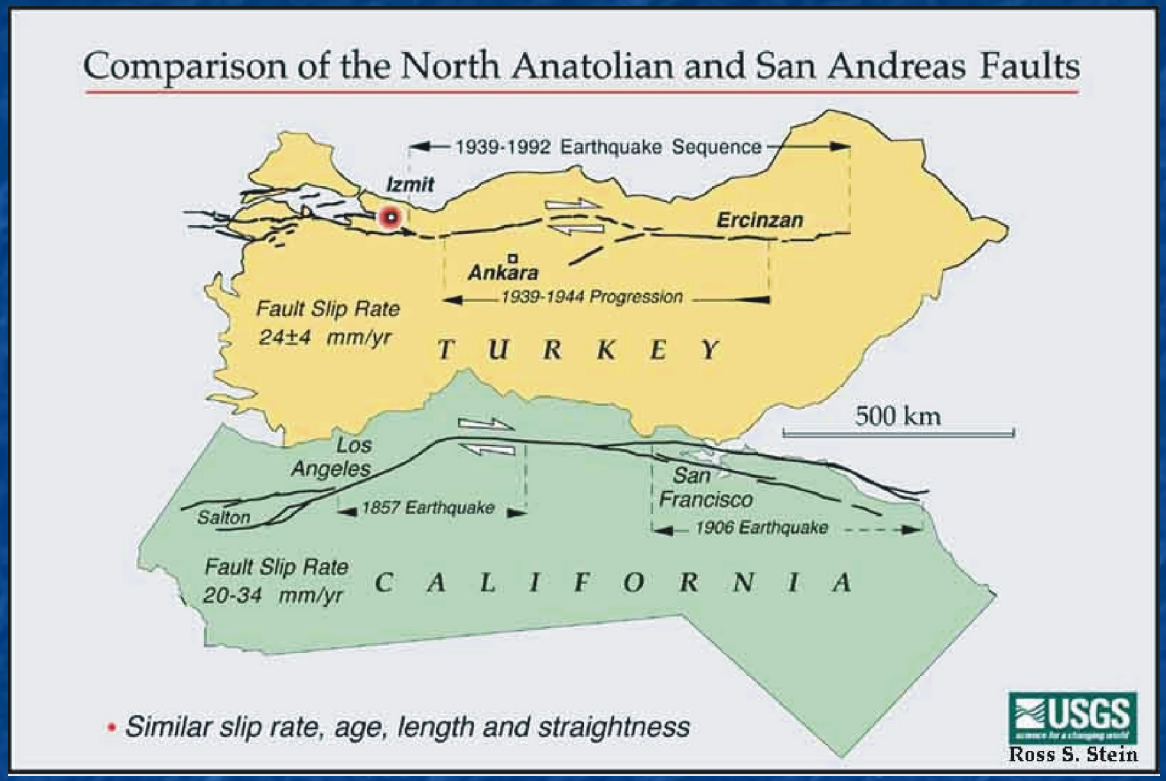
San Francisco, 1906





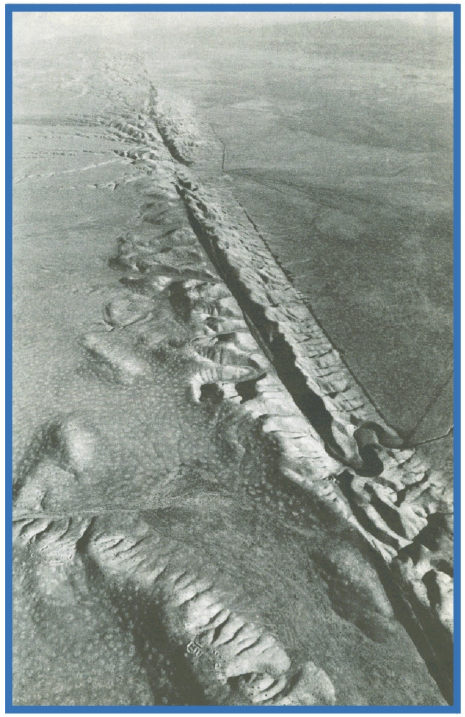
San Andreas

Porównanie uskoków Północnej Anatolii i San Andreas
- podobne przemieszczenie, wiek, długość i liniowość



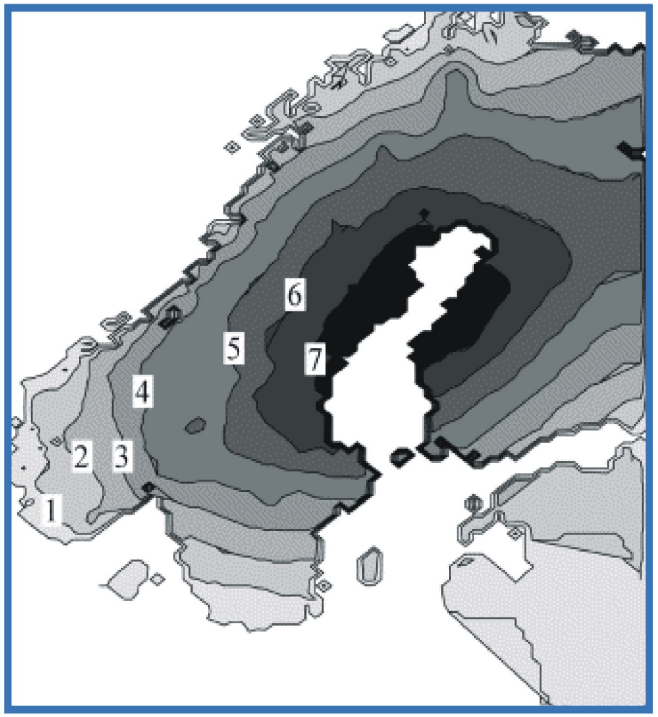
Czy kontynenty się poruszają?
Tak! A czy poruszały się w przeszłości?

Poziome i pionowe przemieszczenia skorupy ziemskiej



Rozłam San Andreas

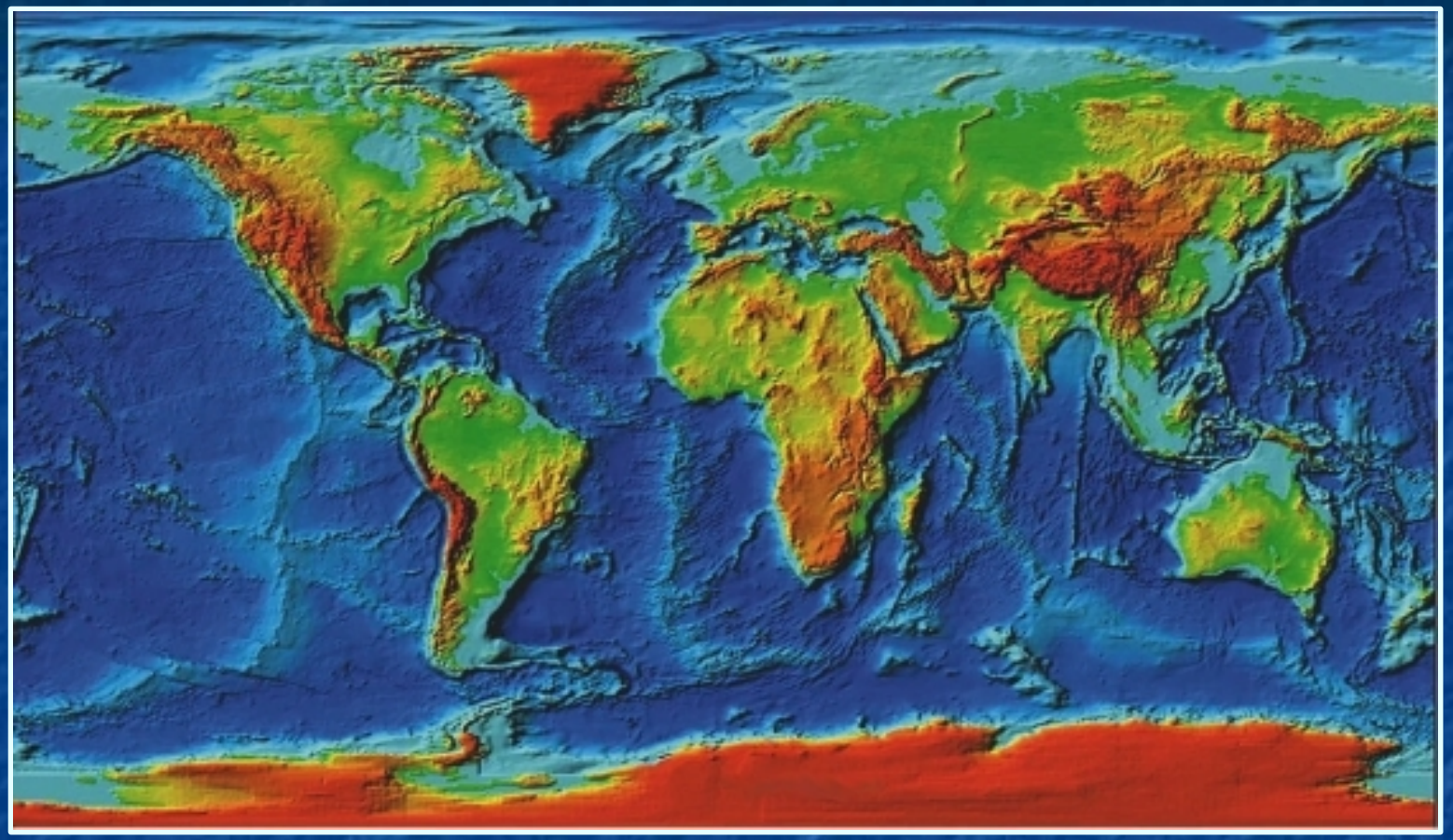




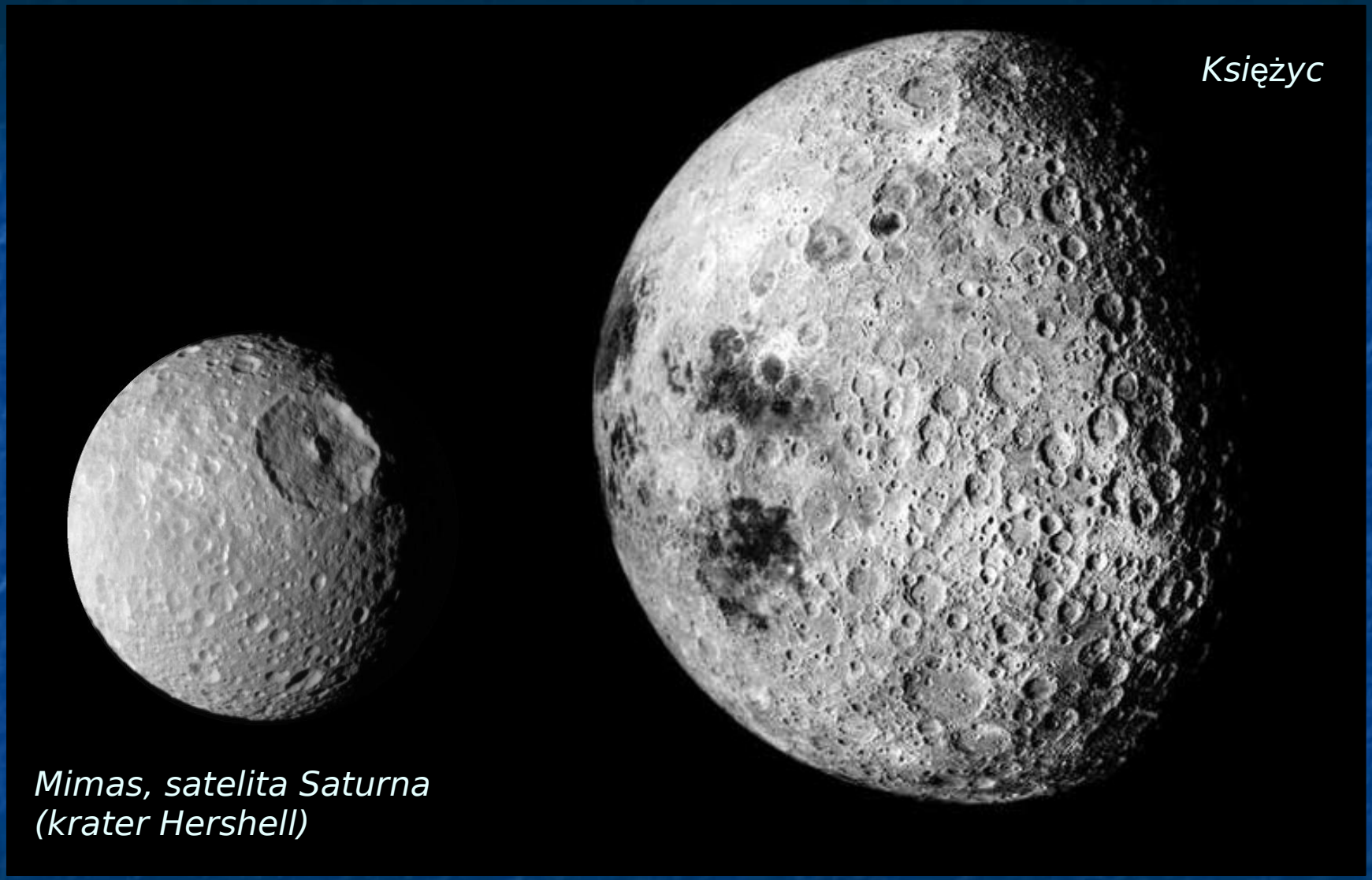
Wynurzanie Fennoskandii
(w mm/rok)

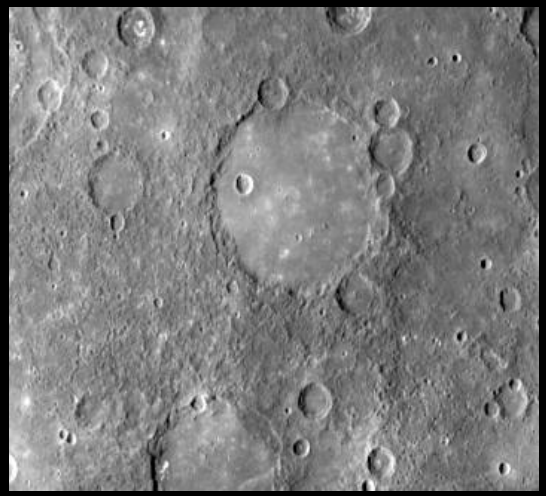
Przemieszczanie kontynentów w przeszłości - fakty

Powierzchnia Ziemi

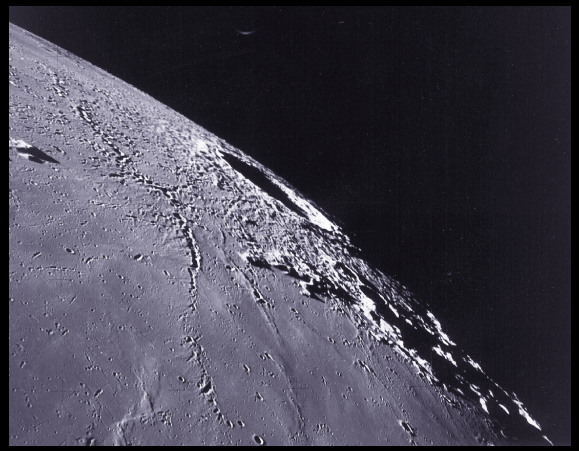


"niziny" i "góry" na kontynentach i oceanach


Księżyc
Mimas, satelita Saturna
(krater Hershell)



Merkury - krater uderzeniowy





Kopernik - krater uderzeniowy na Księżycu

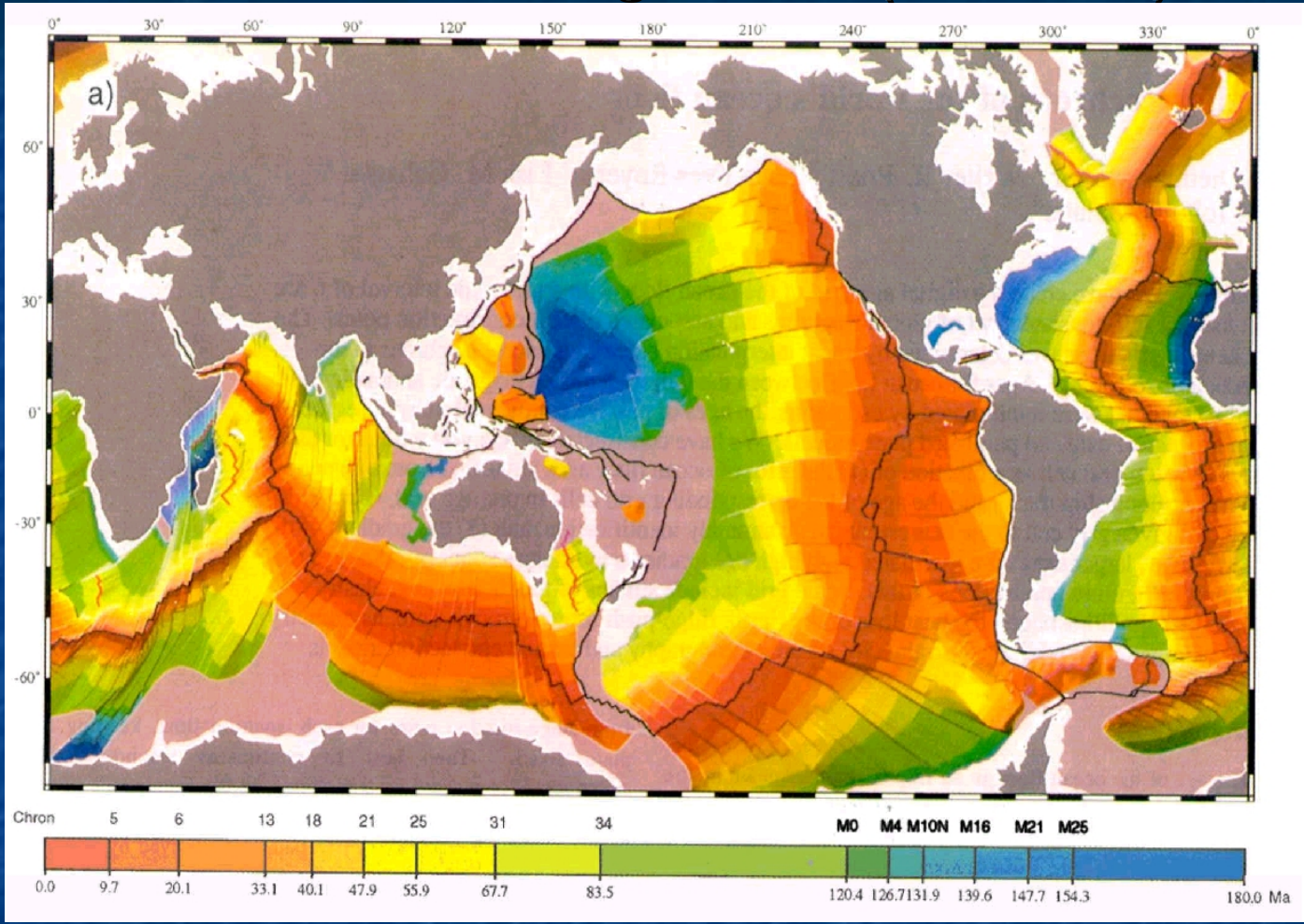


Krater uderzeniowy w Arizonie



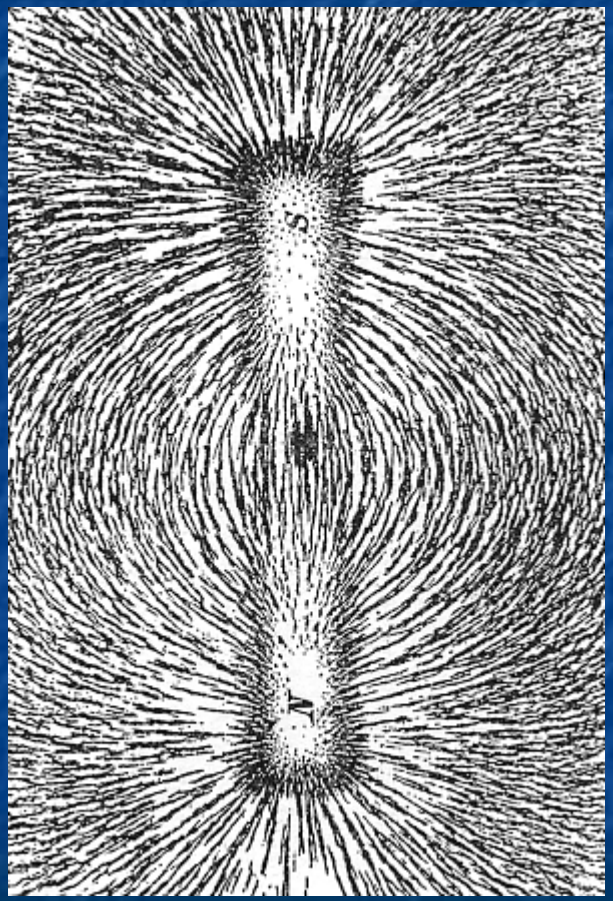
Krater uderzeniowy na Księżycu

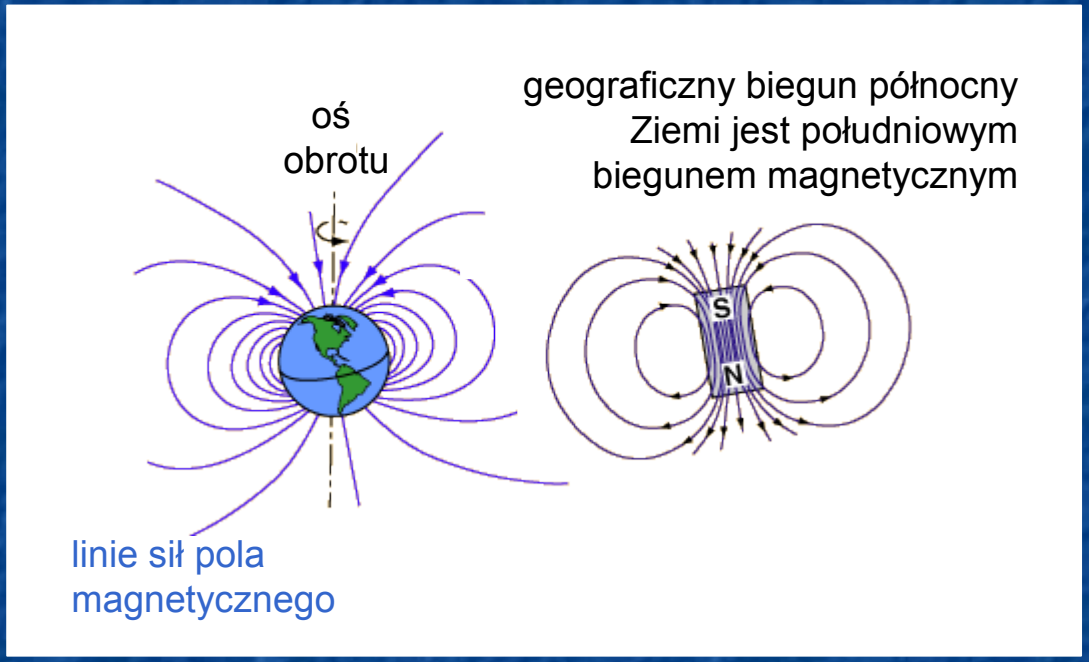
Wiek dna oceanicznego Ziemi (w mln lat)



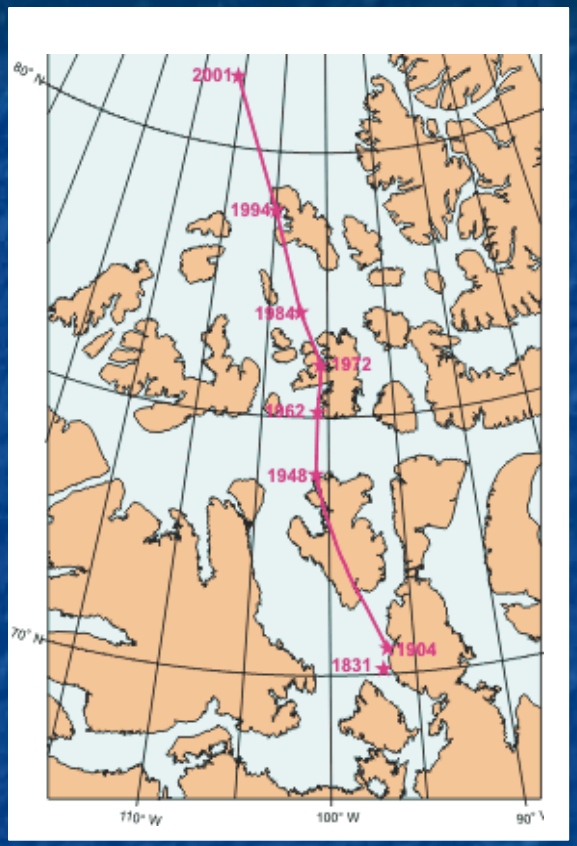
najstarszy ocean ma 180 mln lat, starszych nie ma ...

Pole magnetyczne Ziemi



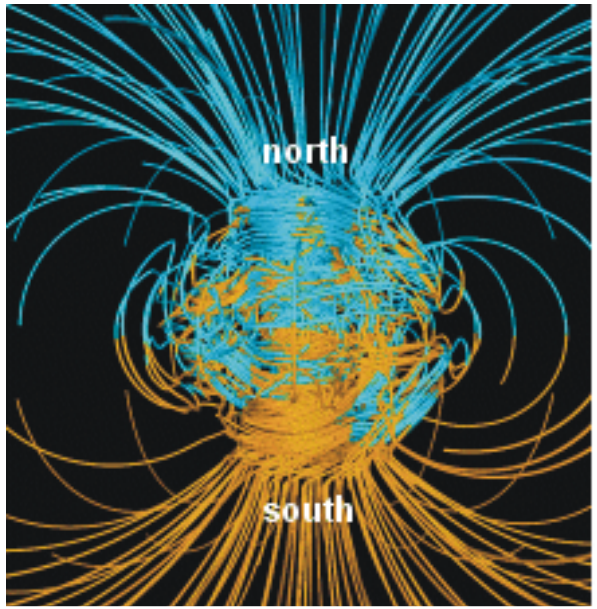


Zmienne pole magnetyczne Ziemi

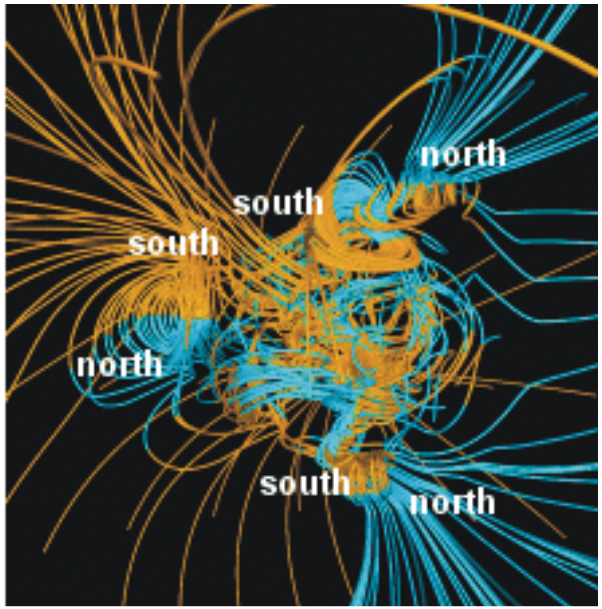


wędrówka ziemskiego
bieguna magnetycznego 1831-2001

model pola magnetycznego Ziemi:

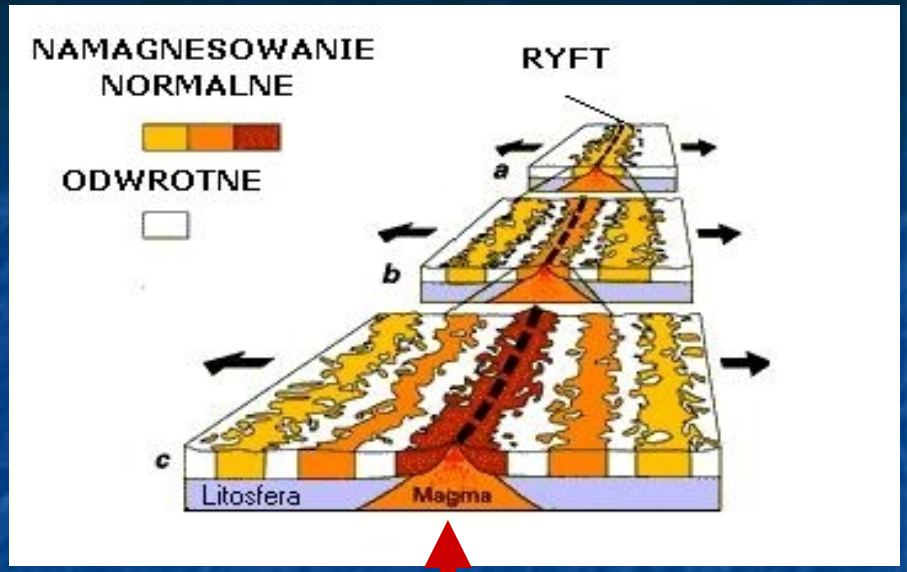


"stabilnego" między odwróceniami ...



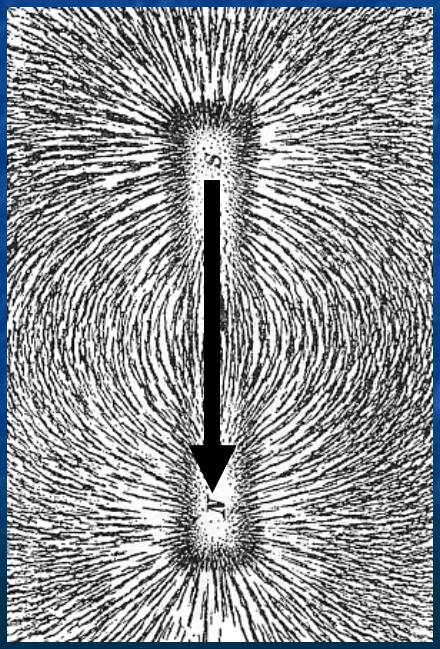
i w trakcie odwracania

Liniowe anomalie magnetyczne dna oceanicznego

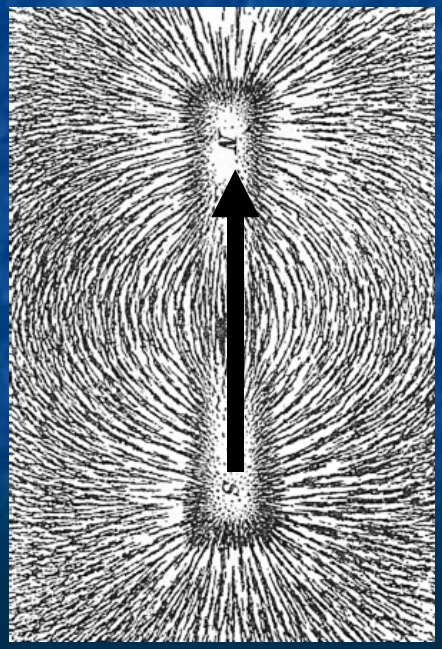


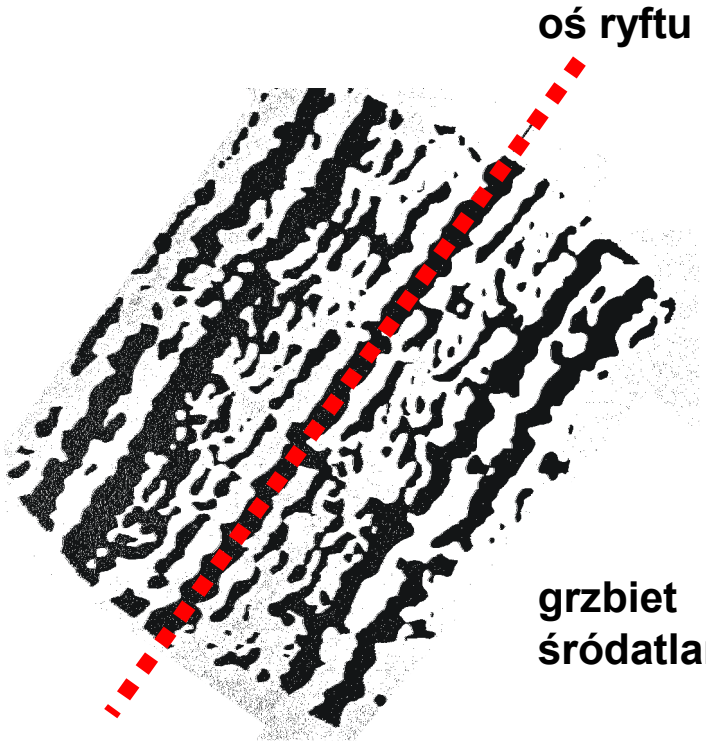
wypływ gorącej magmy w grzbiecie środoceanicznym (ryfcie)

pole normalne



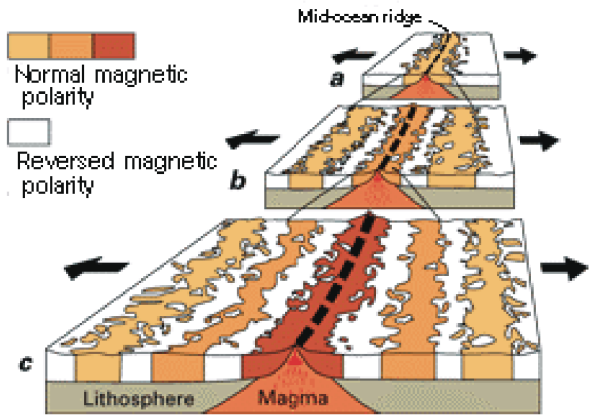
pole odwrócone

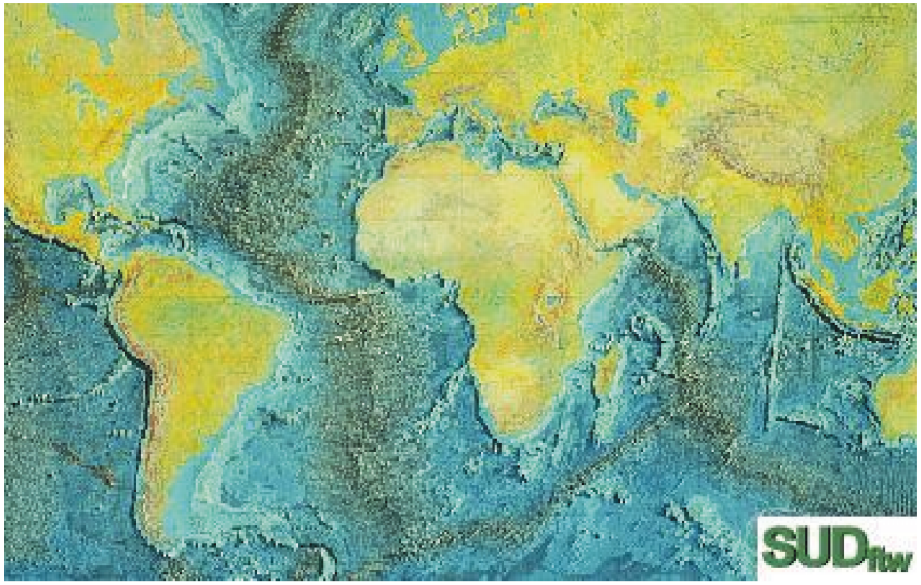


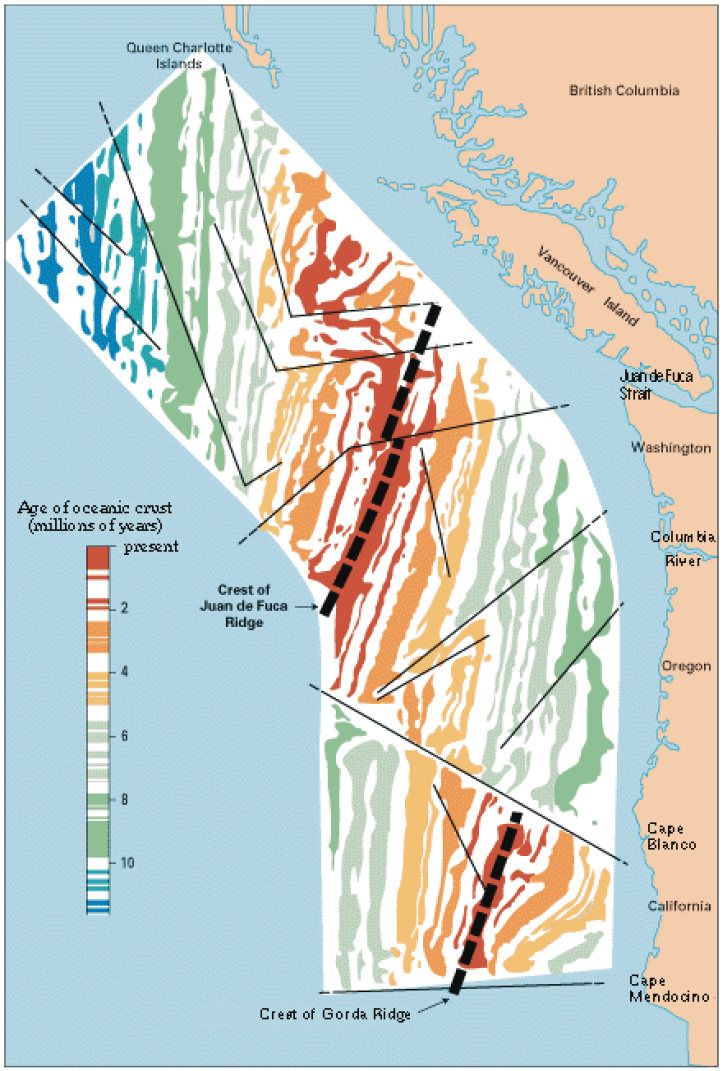


Anomalie magnetyczne na Atlantyku
(Reykjanes Ridge, na SW od Islandii; Vine 1966)

Liniowe anomalie magnetyczne dna oceanicznego



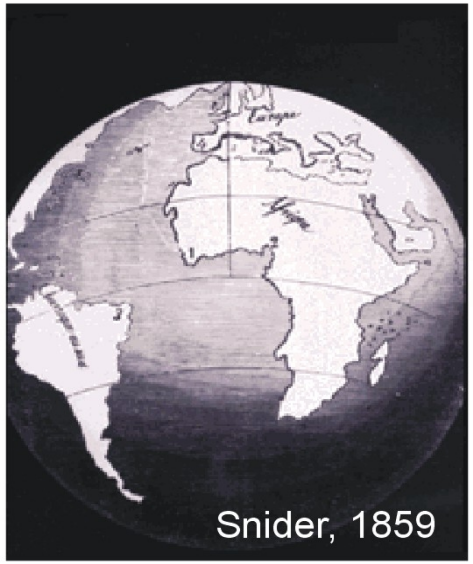


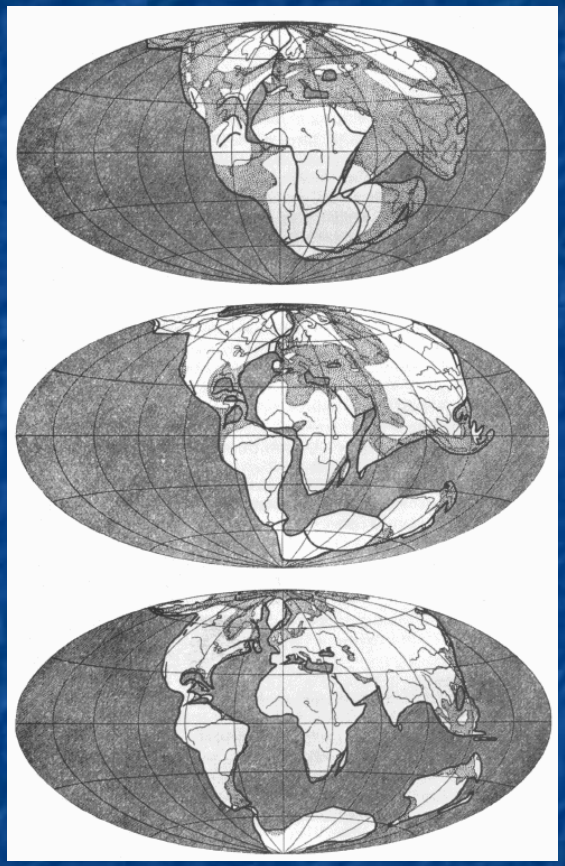


Procesy we wnętrzu Ziemi, konwekcja, dryf kontynentów

"Dopasowane" kontynenty ...





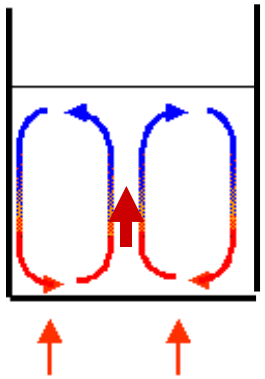




Wegener

Konwekcja





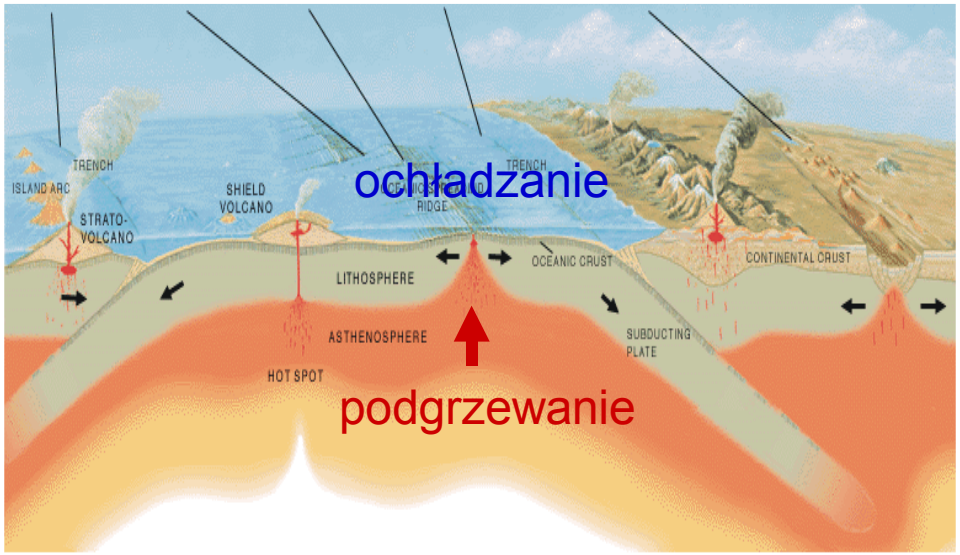
ochładzanie

prąd wznoszący

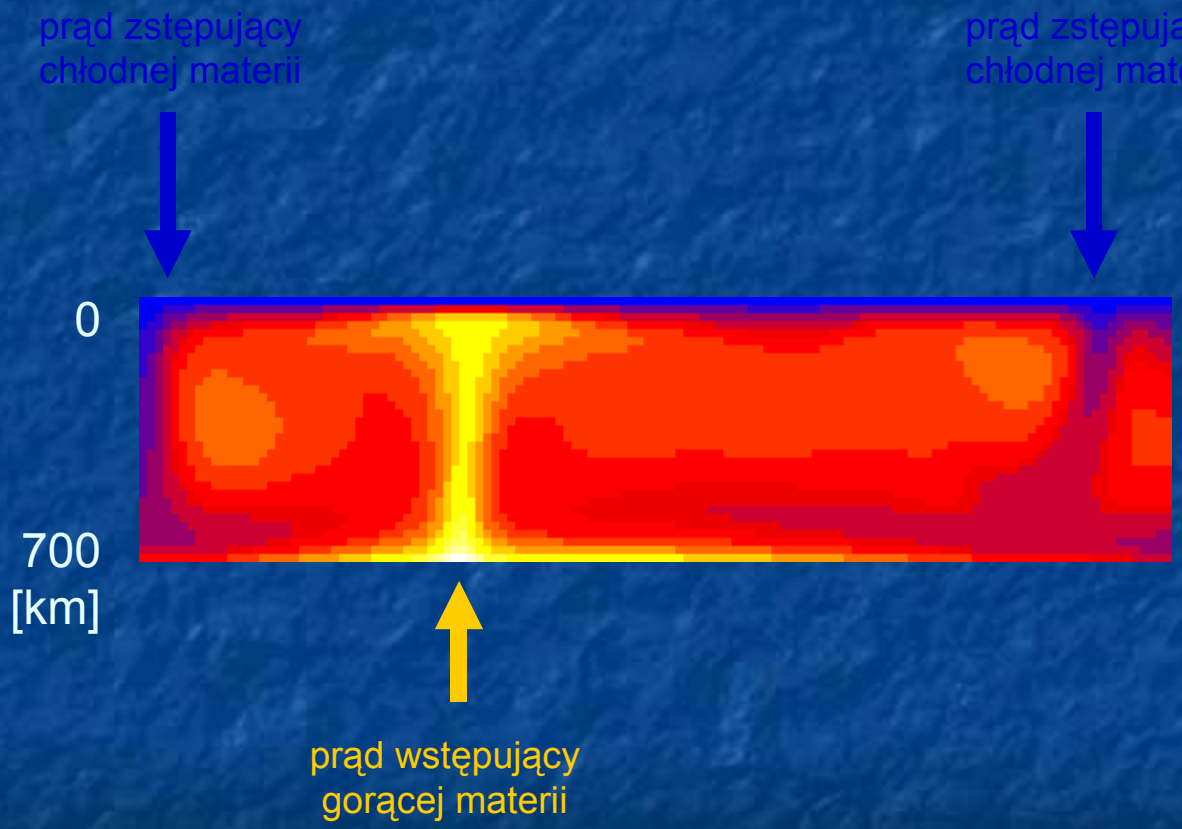
prąd opadający

podgrzewanie

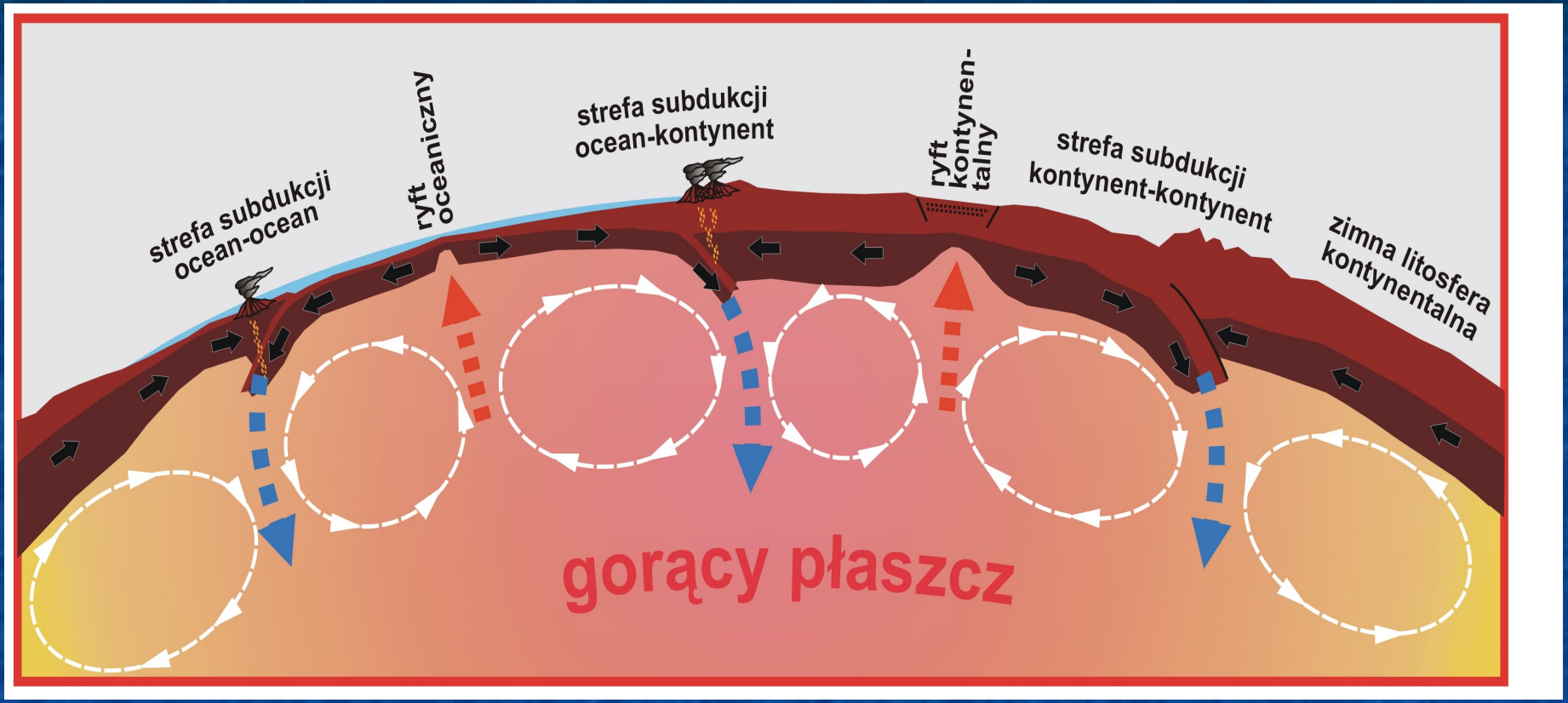
elementy komórki konwekcyjnej we wnętrzu Ziemi



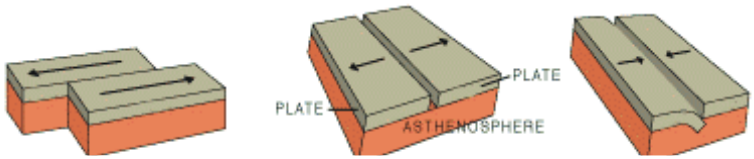
Model konwekcji we wnętrzu Ziemi



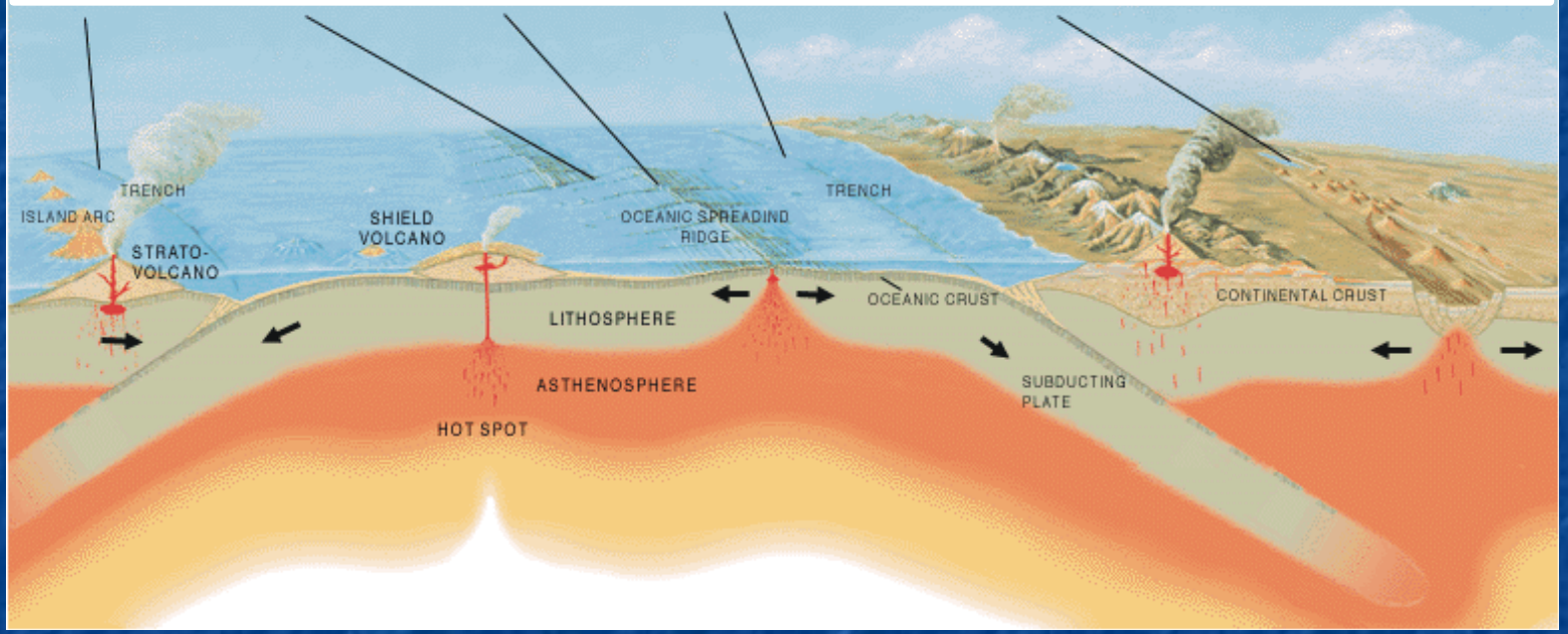
(10 mln lat)

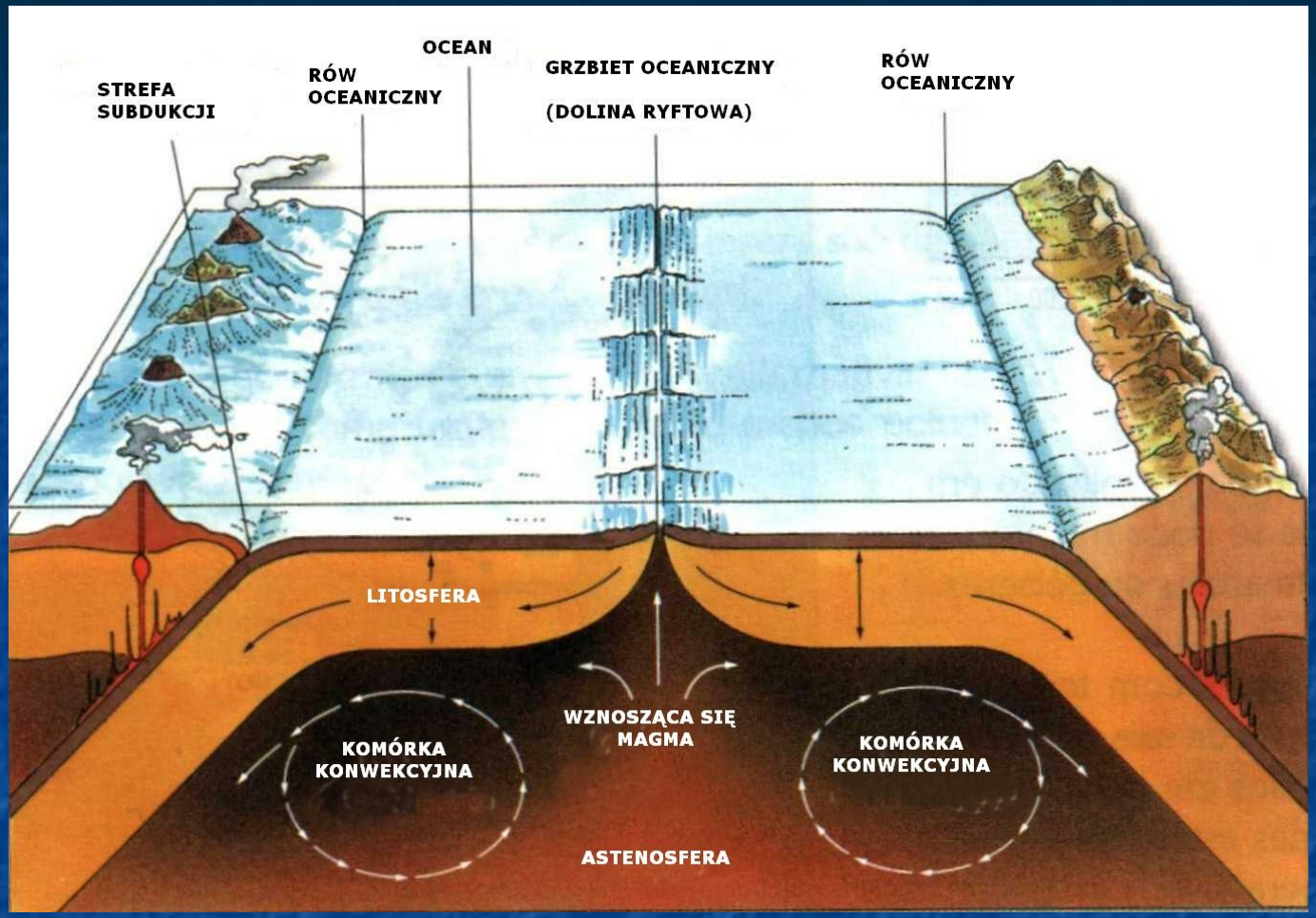

strefa subdukcji
ocean-ocean
ryft
oceaniczny
strefa subdukcji
ocean-kontynent
ryft
kontynen-
talny
strefa subdukcji
kontynent-kontynent
zimna litosfera
kontynentalna
gorący płaszcz

uskok przesuwczy *ryft* *strefa subdukcji*



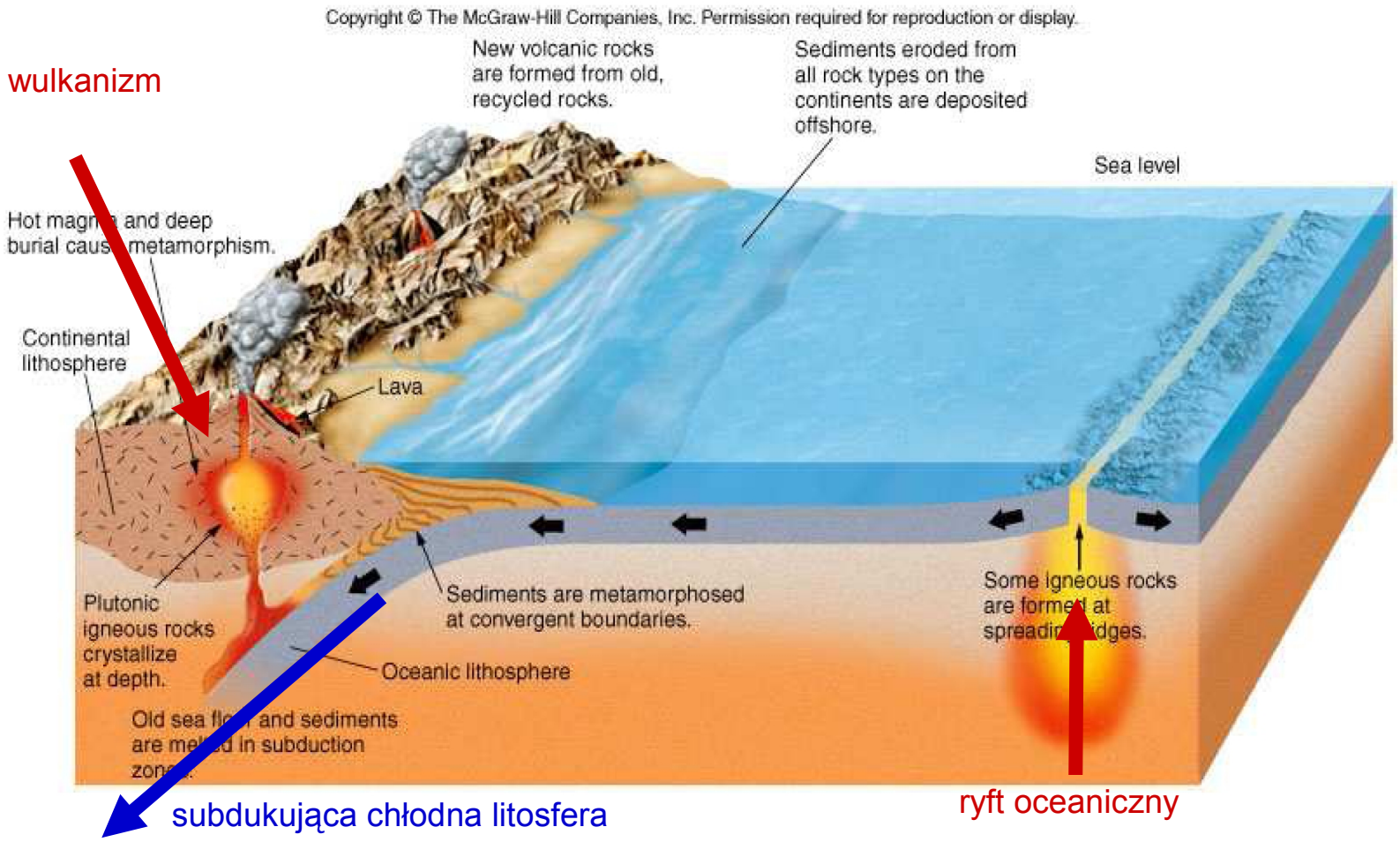
ocean-ocean *grzbiet śród-oceaniczny* *strefa subdukcji* *ryrf kontynentalny*





Komórki konwekcyjne w Ziemi: grzbiet, strefa subdukcji, rów oceaniczny i dolina ryftowa

wulkanizm



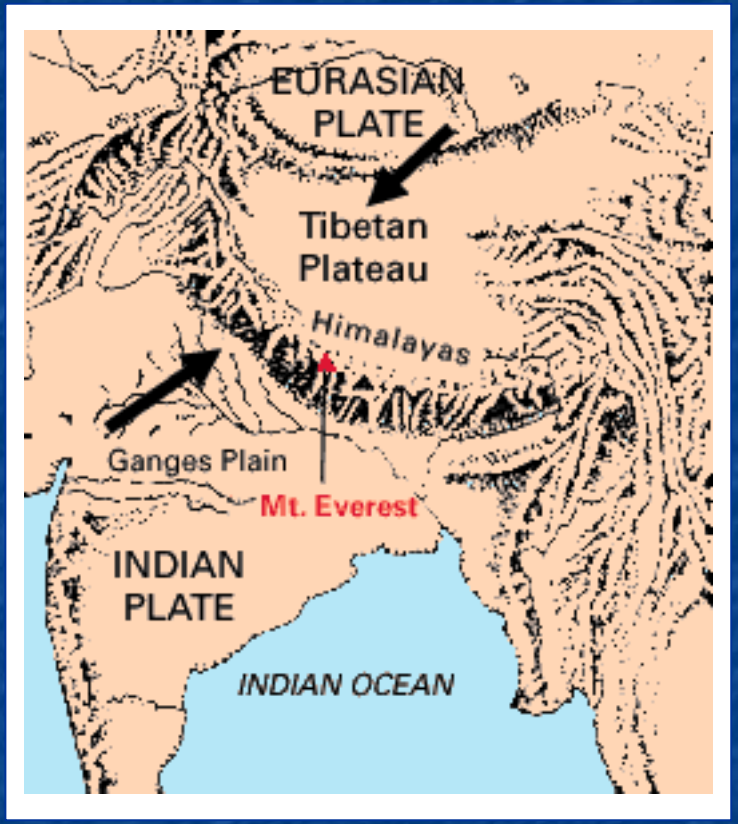
subdukująca chłodna litosfera

ryft oceaniczny

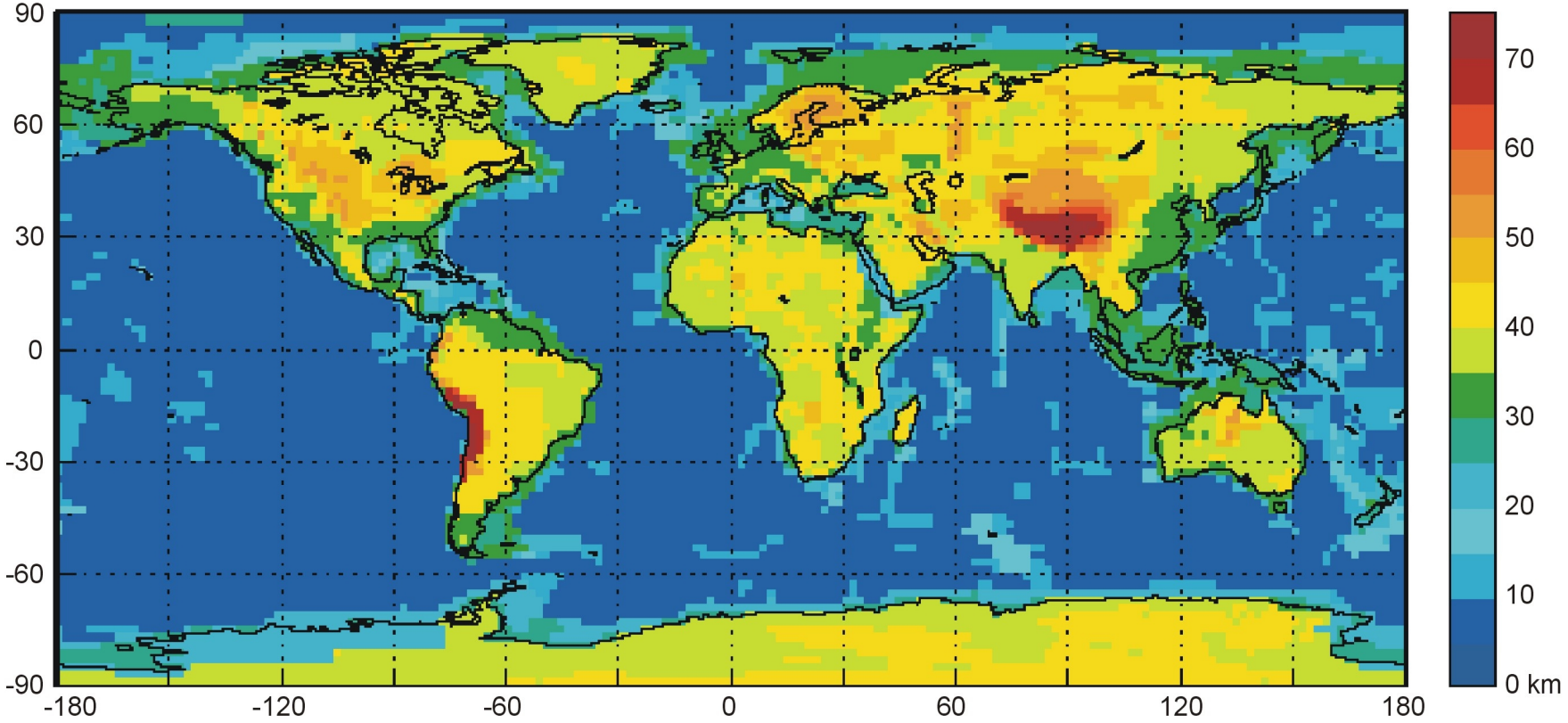
subdukcja ocean – ocean



Kolizja płyty indyjskiej z płytą euroazjatycką

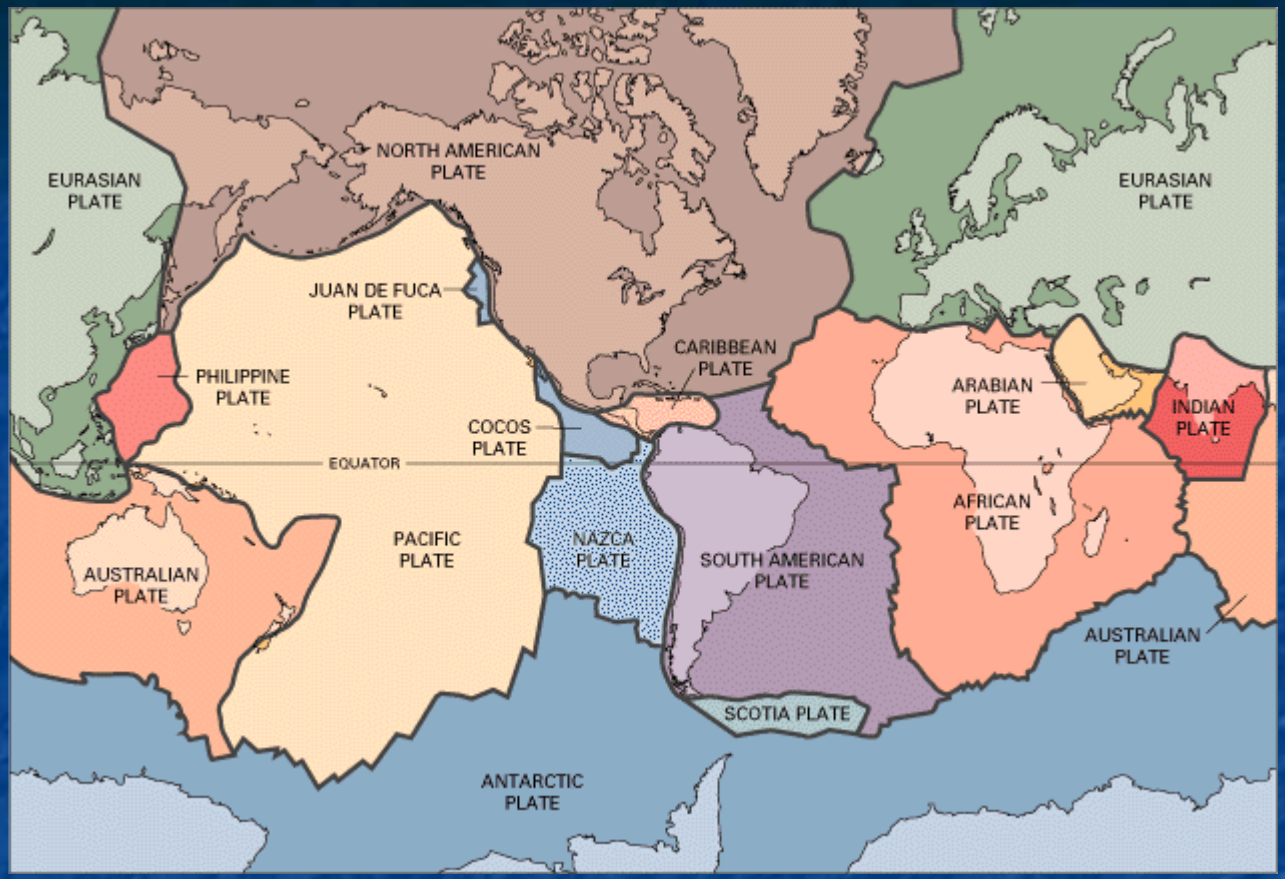


Grubość skorupy ziemskiej [w km]



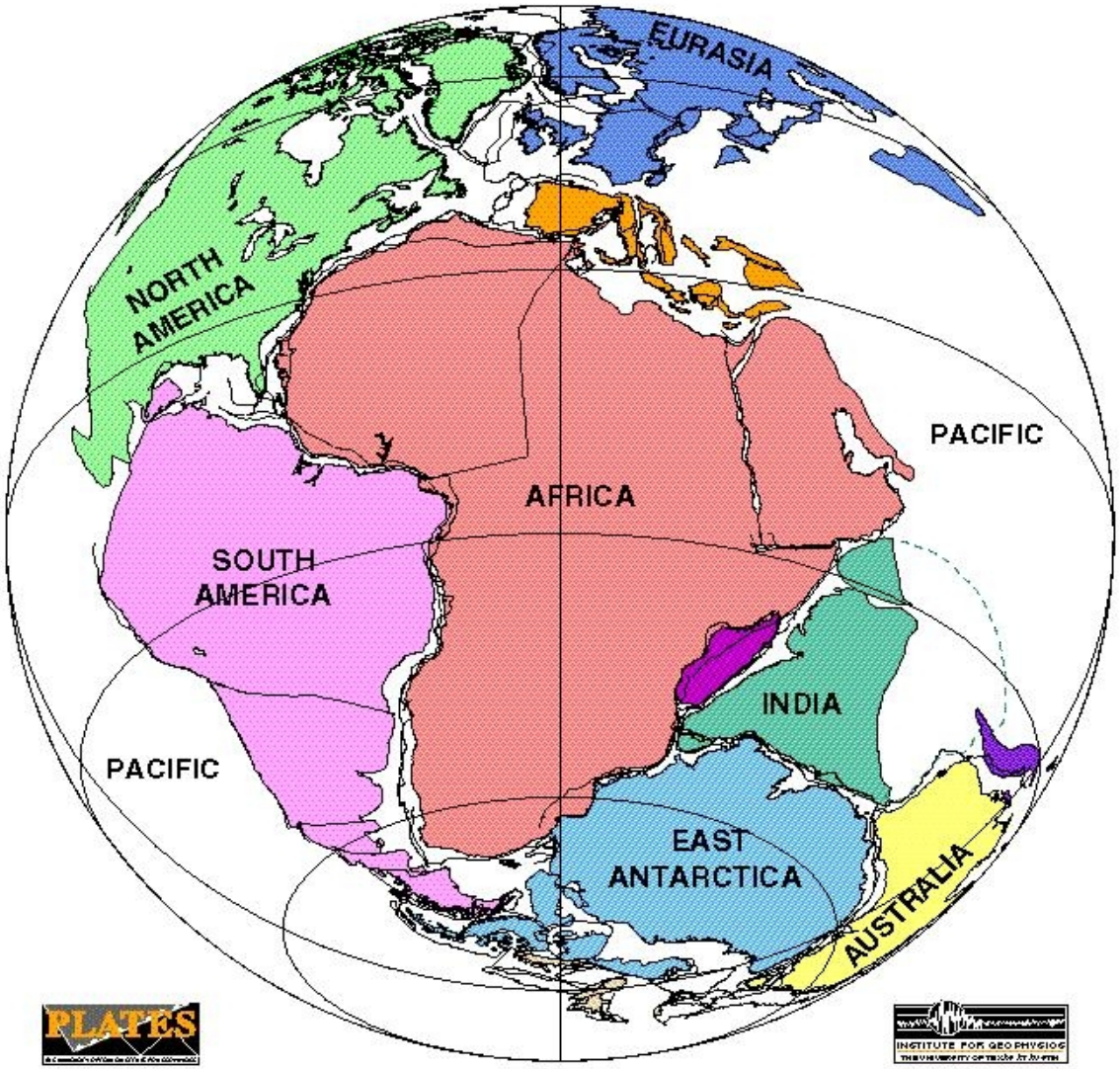
(2°x2°; Laske, 2002; Mooney i in. 1998)

Płyty litosferyczne



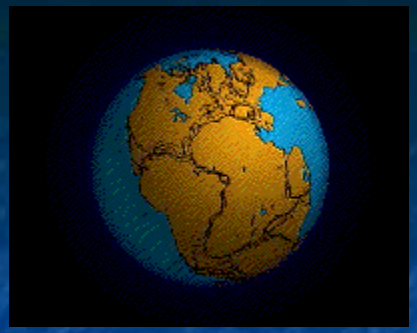


PANGEA

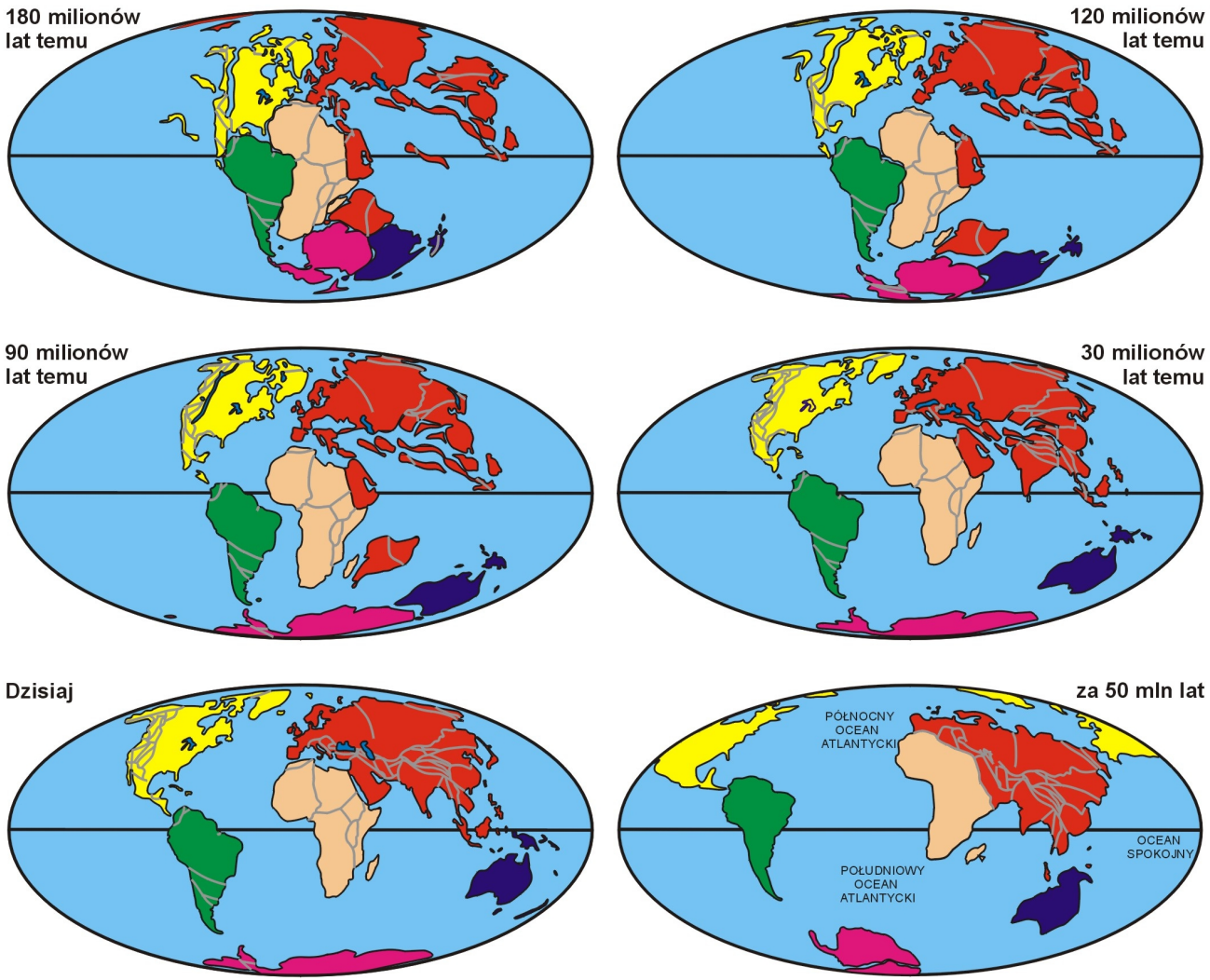

EURASIA
NORTH AMERICA
PACIFIC
AFRICA
SOUTH AMERICA
INDIA
PACIFIC
EAST ANTARCTICA
AUSTRALIA
PLATES
INSTITUTE FOR GEOPHYSICS


AVANT LA SEPARATION


APRÈS LA SÉPARATION



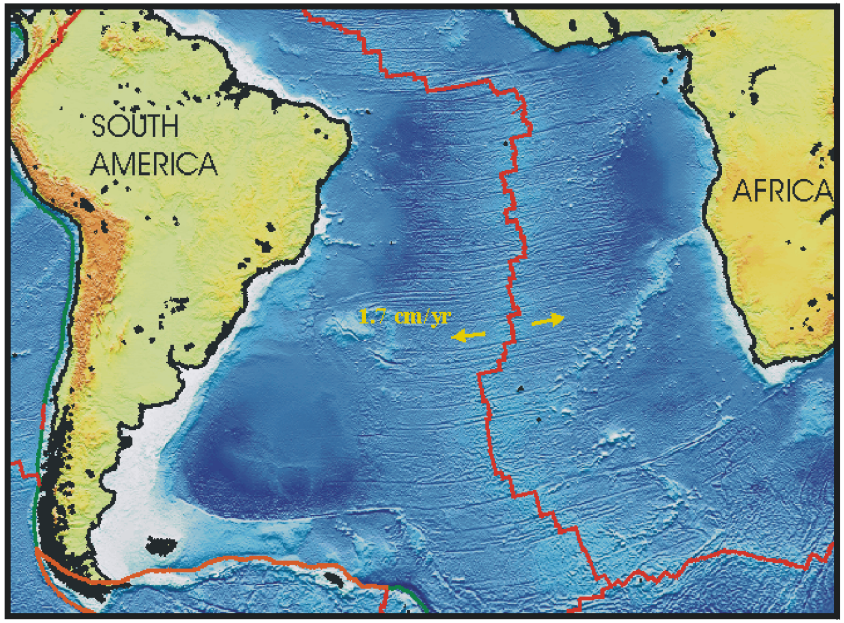
Dryfujące kontynenty

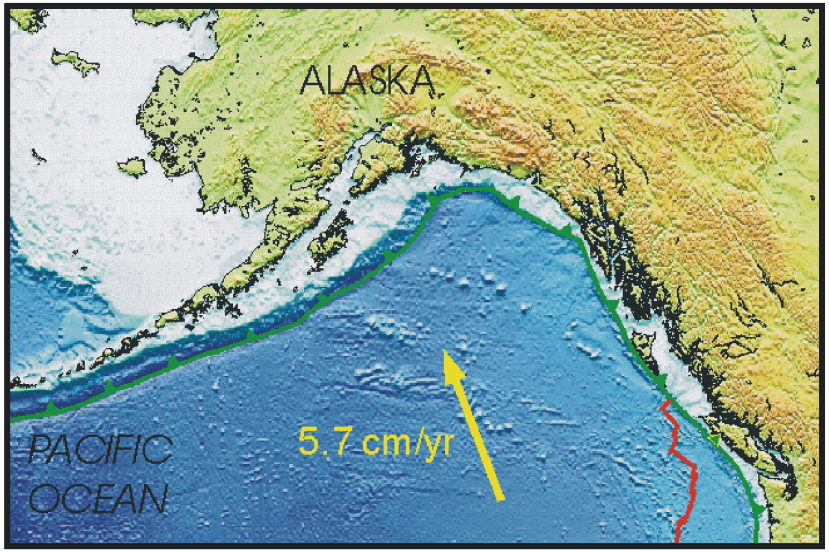


Przyszłość dryfujących kontynentów

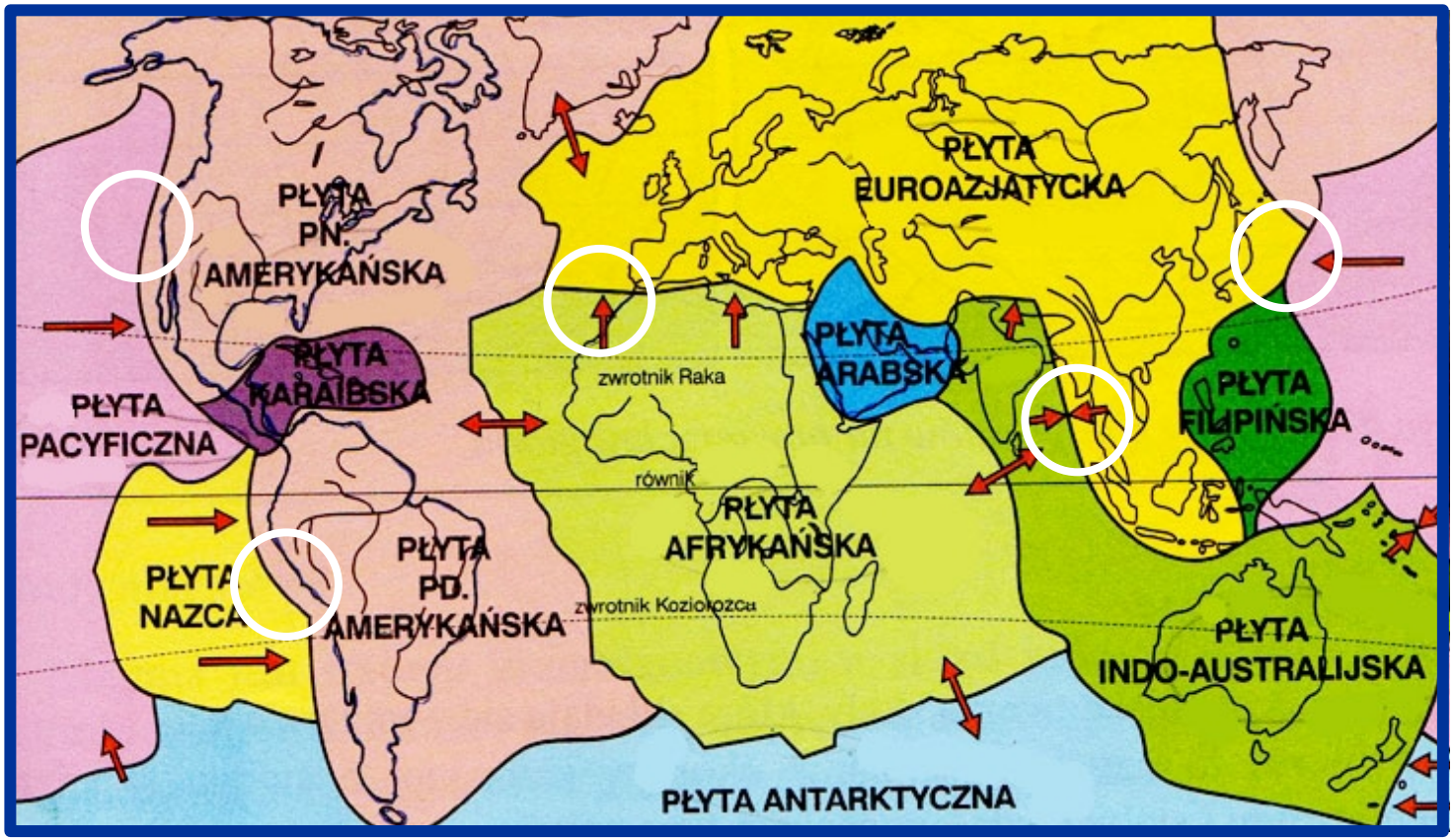
Rozłam transformujący, grzbiet i rów (prędkości płyt)



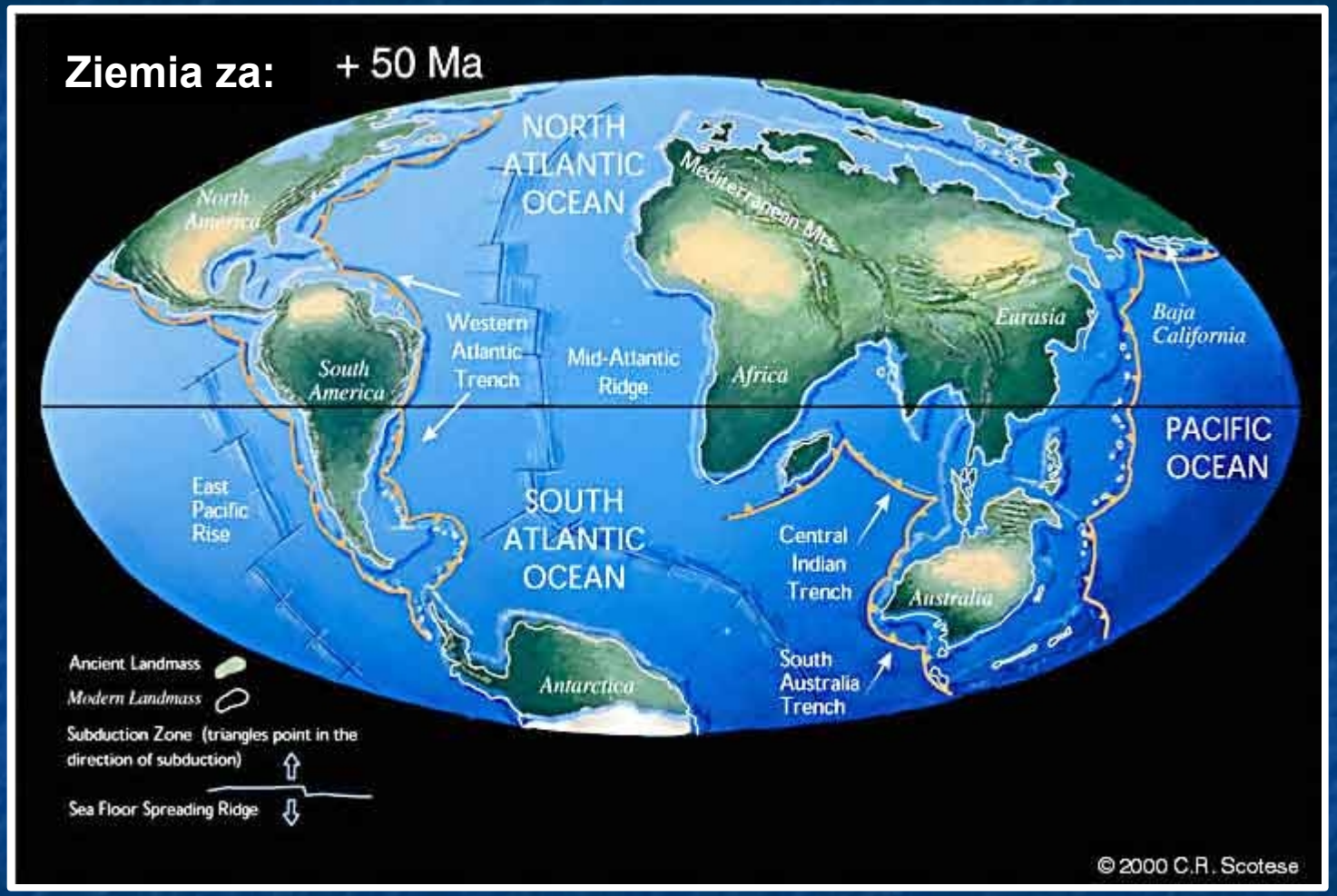


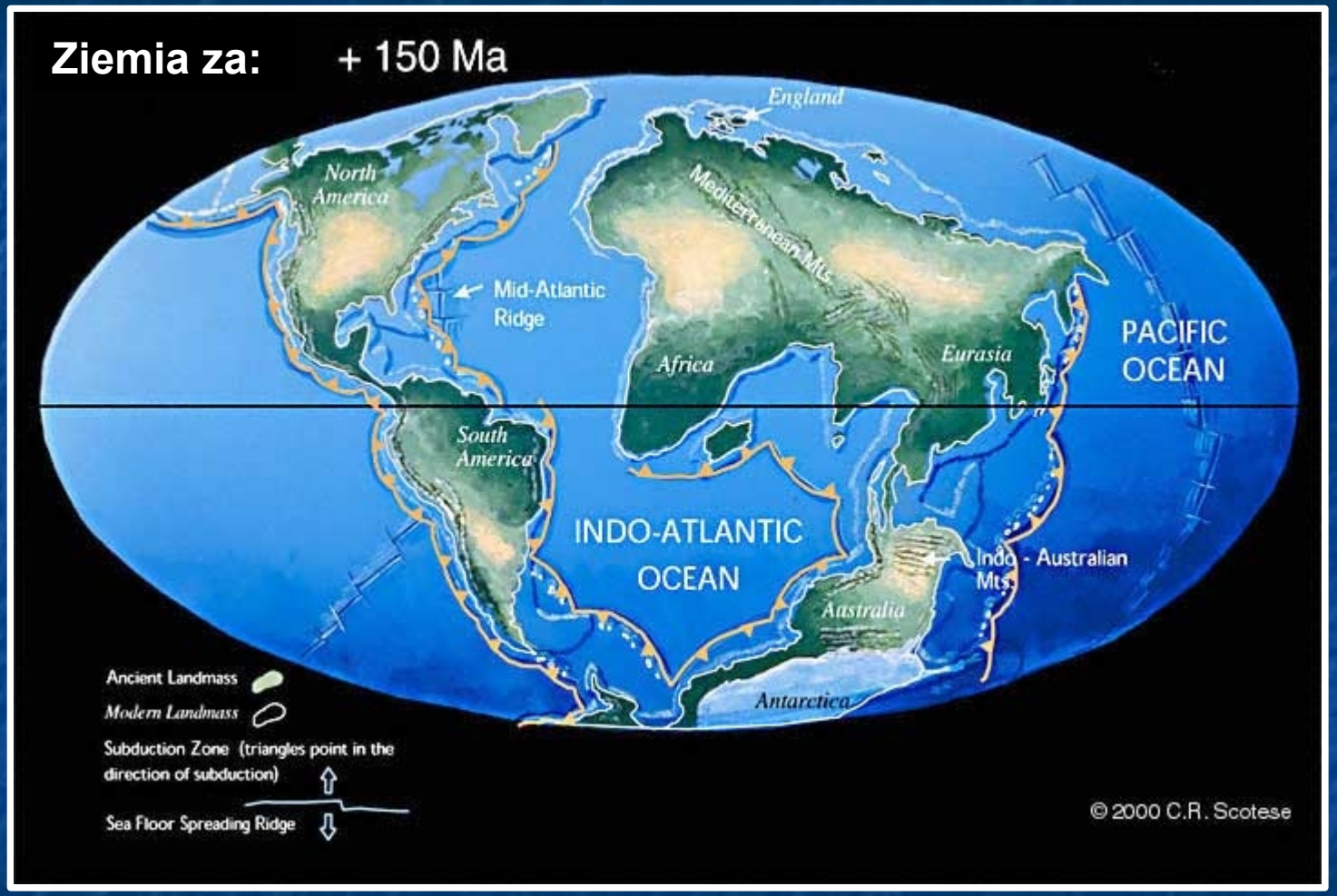


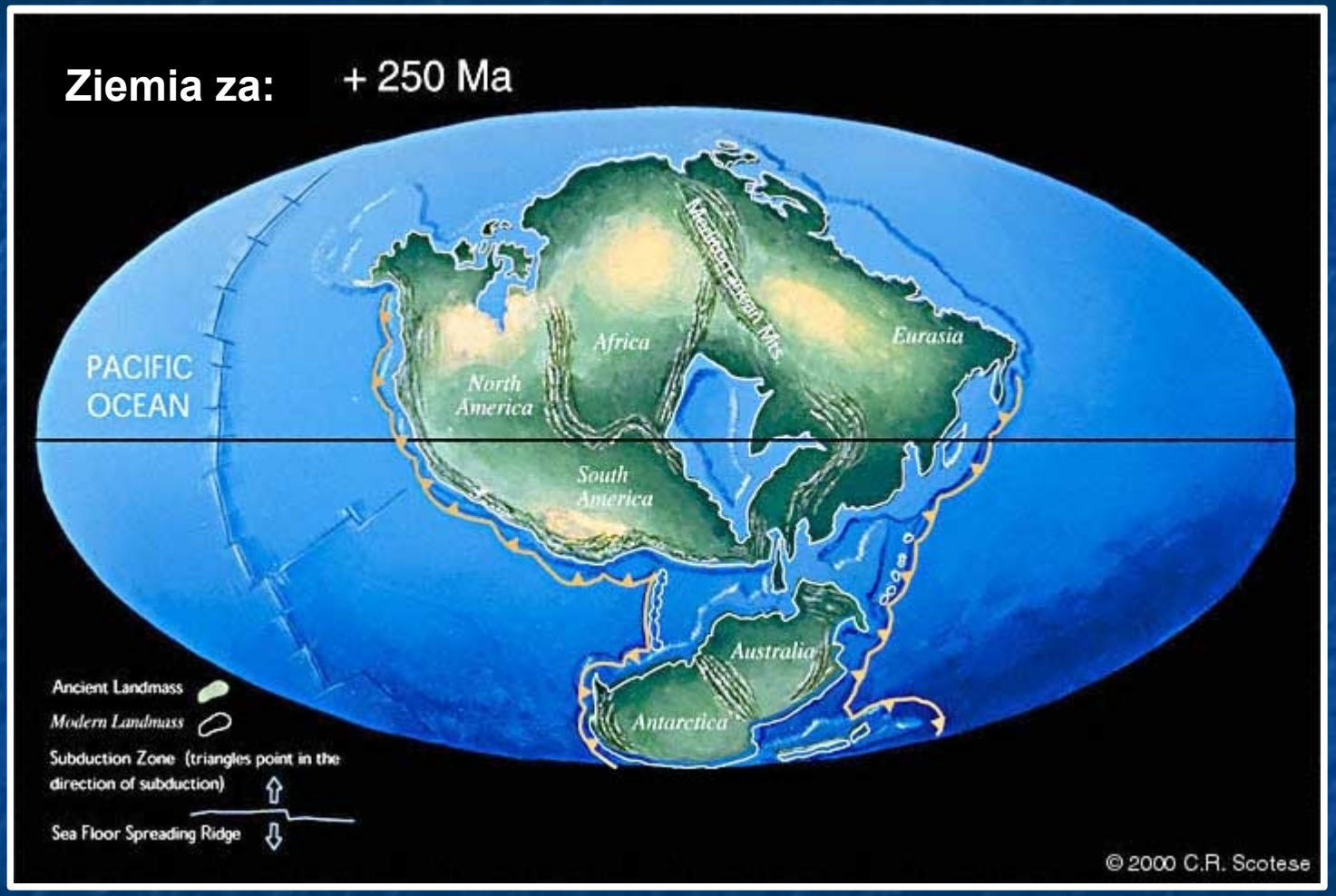
Płyty litosferyczne i ich współczesny ruch



strefy kolizji na oceanie –
potencjalne miejsca wystąpienia silnych trzęsień ziemi i fal tsunami


Ziemia za:
+ 50 Ma
NORTH ATLANTIC OCEAN
North America
Mediterranean Mts.
Eurasia
Baja California
Western Atlantic Trench
Mid-Atlantic Ridge
South America
Africa
PACIFIC OCEAN
East Pacific Rise
SOUTH ATLANTIC OCEAN
Central Indian Trench
Australia
Antarctica
South Australia Trench
Ancient Landmass
Modern Landmass
Subduction Zone (triangles point in the direction of subduction)
Sea Floor Spreading Ridge
© 2000 C.R. Scotese


Ziemia za: + 150 Ma
England
North America
Mediterranean Mts.
Mid-Atlantic Ridge
Africa
Eurasia
PACIFIC OCEAN
South America
INDO-ATLANTIC OCEAN
Indo - Australian Mts.
Australia
Antarctica
Ancient Landmass
Modern Landmass
Subduction Zone (triangles point in the direction of subduction)
Sea Floor Spreading Ridge
© 2000 C.R. Scotese


Ziemia za: + 250 Ma
PACIFIC OCEAN
Africa
Eurasia
North America
South America
Australia
Antarctica
Ancient Landmass
Modern Landmass
Subduction Zone (triangles point in the direction of subduction)
Sea Floor Spreading Ridge
© 2000 C.R. Scotese

Koniec



Podstawowe źródła



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