1-4 Geology and Geological Structure of Paraná Basin

1-4-1 Tectonic Province of the South American Plate

(1) Effective Elastic Thickness of Lithosphere

M.S.M. Mantovani et al. (2001) calculated the effective elastic thickness (Te) of the South American plate using the tidal gravity anomaly, and discussed the relation to the tectonic province.

The lithosphere is the outermost thin viscoelastic plate of the Earth. The underlying asthenosphere maintains the hydrostatic balance supporting the lithosphere Mass by buoyancy. The elasticity of the lithosphere is shown by flexural rigidity (D). D acts as the function of temperature gradient. Consequently, a cold lithosphere is expected to be strong and/or thick and a hot lithosphere is expected to be weak and/or thin. This D is commonly obtained by the coherence method, comparing the spectral distribution of gravity and topography. Ideally, for a maximum coherence value (= 1) between the two distributions, a lithospheric load is totally supported by local isostasy (D→0) , while at its minimum (coherence = 0) the lithosphere block will support any load without deflection (D→∞). The relation between flexural rigidity (D) and the effective elastic thickness (Te) of the lithosphere is shown in the following equation.

$$T_e = \left[12D\left(1.0 - \nu^2\right)/E\right]^{1/3} \qquad (1)$$

E : Young's modulus; $1.0\times10^{11}\,\mathrm{N\,m^{-2}}$

ν : Poisson's ratio; 0.25

There is a way to calculate the flexural rigidity D to know the response corresponding to the lithosphere's outer stress except the coherence method. The tidal power of the earth is used as the outer stress. The tidal power of the earth can be measured as the tidal gravity anomaly (TGA). M.S.M. Mantovani et al. (2001) newly devised the Regression method for the calculation of Te, and calculated Te in 50 earth tide observatories in the South America to present Te geotectonic provinces. The former coherence method can't calculate Te within a narrow tectonic unit, but the regression method made it possible.

(2) Earth Tide and Tidal Gravity Anomaly

The earth's tidal gravity is mostly caused by the attractions of the sun and the moon. The component of the earth's tidal gravity caused by the attraction of the moon (M2) can be observed more precisely than those caused by attractions of the other celestial bodies. The

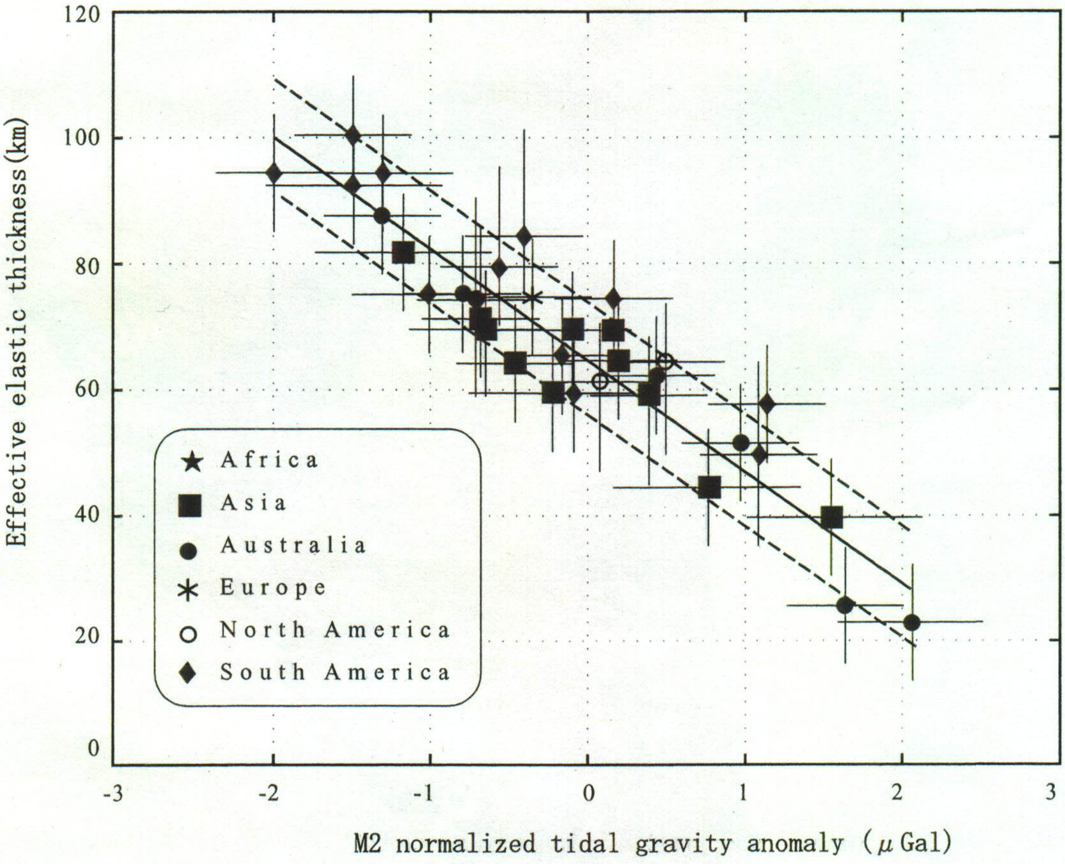

Fig. II-1-4-1 World data set regression line (solid) and the standard deviation (dashed curves) of the calculated Te for 36 stations (M.S.M. Mantvani et al., 2001)

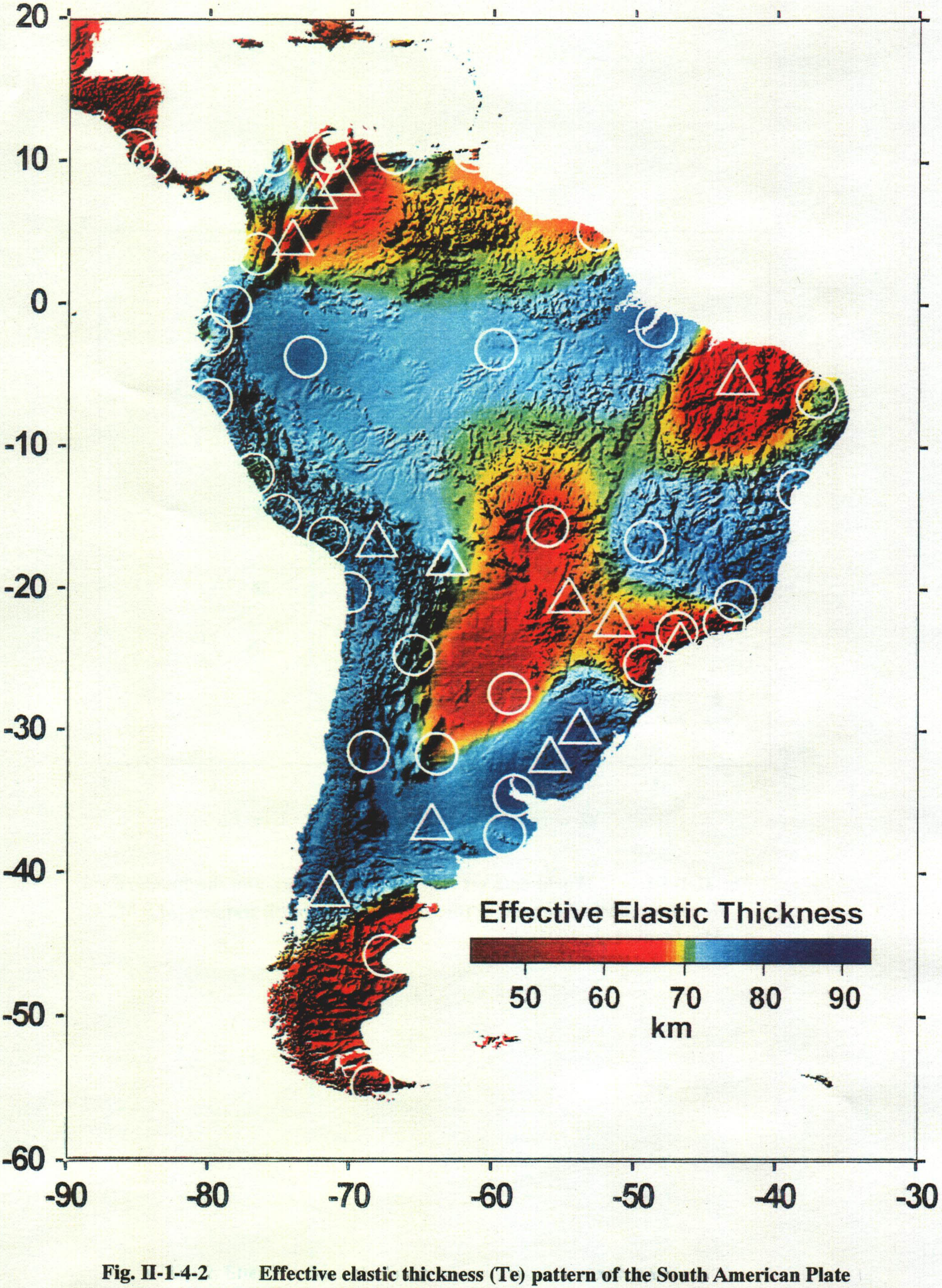

Fig. II-1-4-2 Effective elastic thickness (Te) pattern of the South American Plate
Domains were defined within three intervals of *Te* values:< *Te* 68 km(red: thin and/or hot); 68km< *Te* < 72km (yellow/green) and *Te* > 73km (blue: thick and/or rigid). White circles are locations of tidal gravity stations data and triangles are locations where exist published *Te* estimates in correspondence with tidal gravity station. (M.S.M. Mantovani et al., 2001)

value of tidal gravity of the M2 component (M (ϕ)) can be derived by using the following equation. A = (A, α) shows the observation data corresponding to M2 tidal gravity, M = (M, μ) the calculated value corresponding to M2 tidal gravity, and L = (L, λ) the effect of the ocean load. The phase μ of M is assumed by 0. Under these conditions, TGA means the discrepancy between the observation data and calculation value of tidal gravity.

$$M(\phi) = 87.00\frac{r(\phi)}{a_E}\cos^2\phi \ldots\ldots\ldots\ldots\ldots \mu\ Gal \qquad (2)$$

$$TGA = A\cos\alpha - L\cos\lambda - M \qquad (3)$$

The Trans World Tidal Gravity Profile (TWTGP, 300 points, A) is Maintained by the International Center for Earth Tides (ICET) in Brussels. The TGA values were calculated using TWTGP data of 50 observatories in South America. The Te values at many observatories on each continent have been calculated using the Coherence method and Admittance method.

For the 36 observatories in the world which have the Te data, the correlation diagram between TGA and Te was made and the equation (4) between TGA and Te approximated by the least mean square method was calculated (Fig. II-1-4-1). Here, cos2ϕ is a term to adjust the latitude change of M2 tidal gravity. The correlation coefficient between TGA and Te is 0.88. The calculated Te values are shown in Fig. II-1-4-2.

$$T_e = 65.32 - 17.54\frac{TGA}{\cos^2\phi} \qquad (4)$$

(3) Effective Elastic Thickness of the South American Plate

The South American plate can be classified into a high Te zone (low temperature and thick lithosphere; Te > 72 km, blue part) and a low Te zone (high temperature and thin lithosphere; Te < 68 km, red part) (Fig. II-1-4-2). Compared with the geological structural map, the high Te zone corresponds to the Rio de La Plata craton (1.9-2.2 Ga), the San Francisco craton (3.4-2.6 Ga) and the Amazon craton (3.1-2.5 Ga), the collision belts in Proterozoic and most of the Andes mountains (Fig. II-1-4-3). On the other hand, the low Te zone corresponds to the Paraná-Chaco basin, the Ponta Grossa arch, the Paranaiba basin, the Patagonia Peninsula, the coastal zone along the Calibian Sea and the Serra do Mal. The latter is the part where the

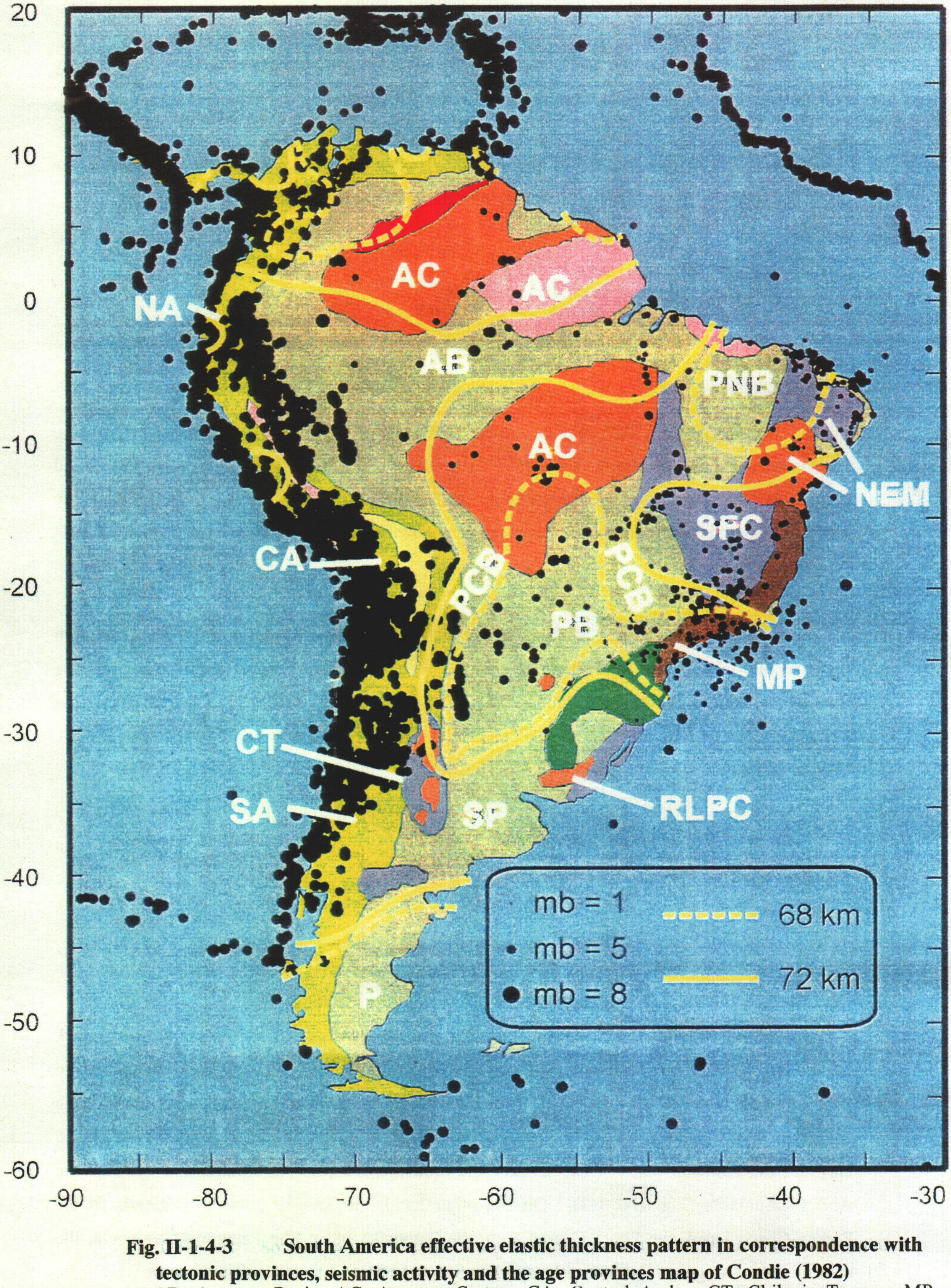

Fig. II-1-4-3 **South America effective elastic thickness pattern in correspondence with tectonic provinces, seismic activity and the age provinces map of Condie (1982)**
AB, Amazon Basin; AC, Amazon Craton; CA, Central Andes; CT, Chilenia Terrane; MP, Mantiqueira Province; NA, Northern Andes; NME, Northeastern Margin of South Atlantic Shield; P, Patagonia; PB, Parana-Chaco Basin; PCB, Phanerozoic collisional belts; PNB, Parnaiba Basin; RLPC, Rio de la Plata Craton; SA, Southern Andes; SFC, Sao Francisco Carton; SP, Southern Province. (M.S.M. Mantovavi et al., 2001)

magma has been active since the Triassic-Cretaceous. The transition Te zone (68 km < Te < 72 km, yellow part and green part) corresponds to the boundary zone of the geological tectonic provinces.

The flood basalt of Paraná-Chaco basin had been most active from 133 to 130 Ma, and had floored among approximately 10 Ma. Most of the lava flows are considered to be originated from the mantle plume. The Te value of the Ponta Grossa arch shows a low value of 58 km. The Ponta Grossa arch is inferred to be the feeder of Paraná flood basalt on the basis of many dykes in the NE-SW direction. The Paraná-Chaco basin shows the low Te values from 47 to 68 km widely. The lithosphere in the Paraná-Chaco basin is thinner under the extensional stress field and the Mantle Material below the basin is considered to exist at the shallower levels.

1-4-2 Geology and Geological Structure of Basement Rock

(1) Geological Structure Province

The Gondowana continent is composed of Archean craton which was made blocks by faults and the surrounding folding zone in the Brazilian-Pan African orogenic movement (800-450 Ma) (Fig. II-1-4-4). A part of the basin in the early Proterozoic to Cambrian was formed in the last jointing stage of Gondowana continent which is composed of clastic rocks, carbonate rocks and igneous rocks. The structures of the basin and the folding zone in the Brazilian-Pan African orogenic movement changed remarkably in the Phanerozoic. The geology and geological structure of Paraná basin is shown in Fig. II-1-4-5.

Paraguay-Araguay Belt: The belt deposited along the south-eastern margin of the Amazon craton in the early Proterozoic to Cambrian. The sedimentary rocks become more abyssal sedimentary facies toward the east. The belt is cut by the transbrazilian fault in the NE-SW direction. The eastern part of the belt bounded by the fault continues below the sediments of the Paraná basin. The belt runs in the N-S direction to Paraguay along the western Margin of the Paraná basin and runs in the ENE-WSW direction along the northern Margin of the Paraná basin.

Western Goias Belt: The belt is located in the northern side of Paraná basin and is composed of orthogneiss, volcanic rocks and sedimentary rocks of the late Proterozoic (930-600 Ma). The volcanic rocks are originated from the origin geochemically. The crust of oceanic origin resulted in the ruputure between the Amazon craton in the west and the San Francisco craton in the east. Many kind of granitic rocks (590-480 Ma) intrude into the belt.

Brazilia Belt: The belt is located in the north-eastern margin of the Paraná basin as well as in the western margin of San Francisco craton. The belt is folded and thrusted, and is composed of mica gneiss and diabase are. The belt seem to have been once a subduction zone.

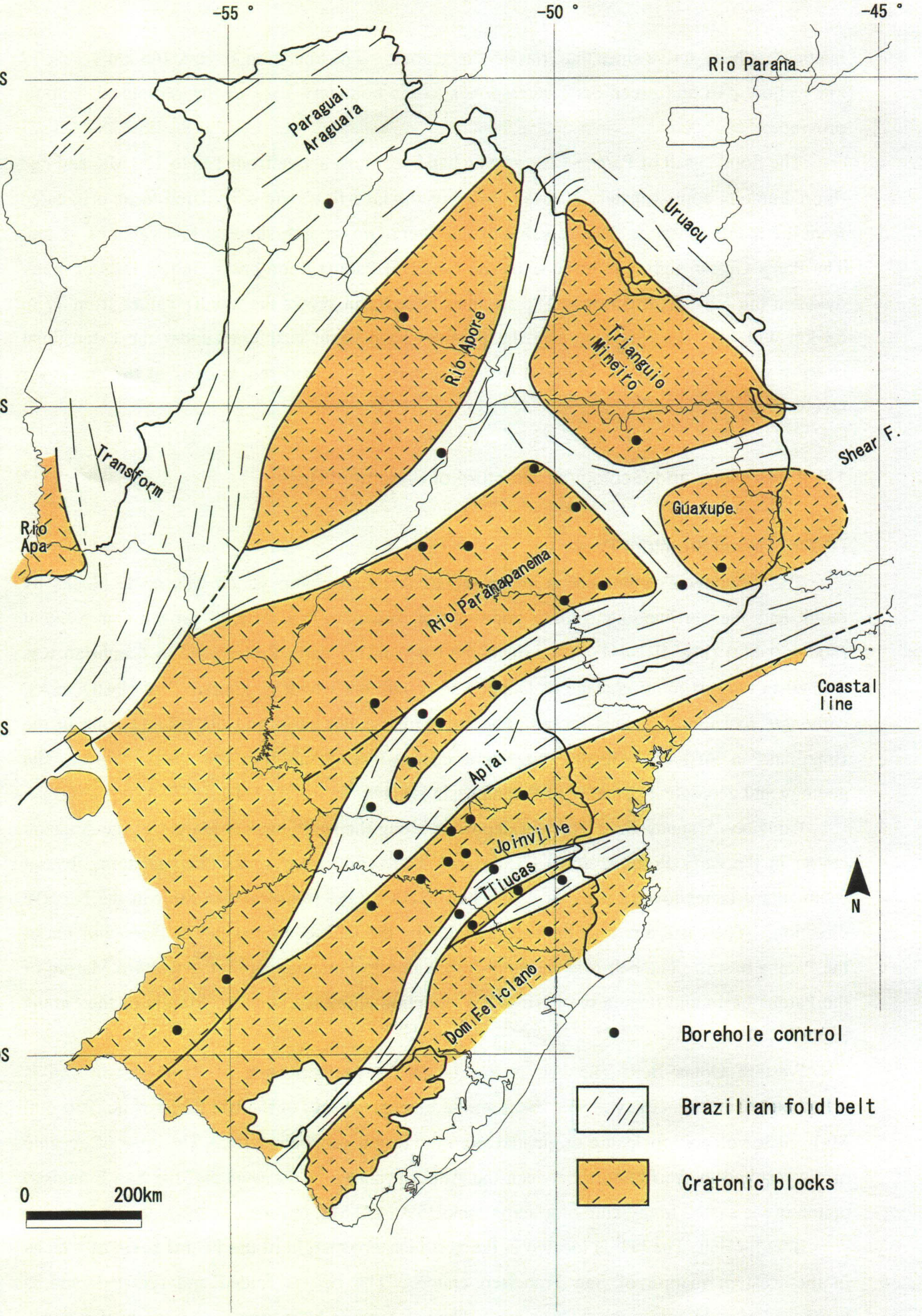

Fig. II-1-4-4 Schematic map of basement and tectonic framework of the Paraná basin (E.J. Milani, 1998)

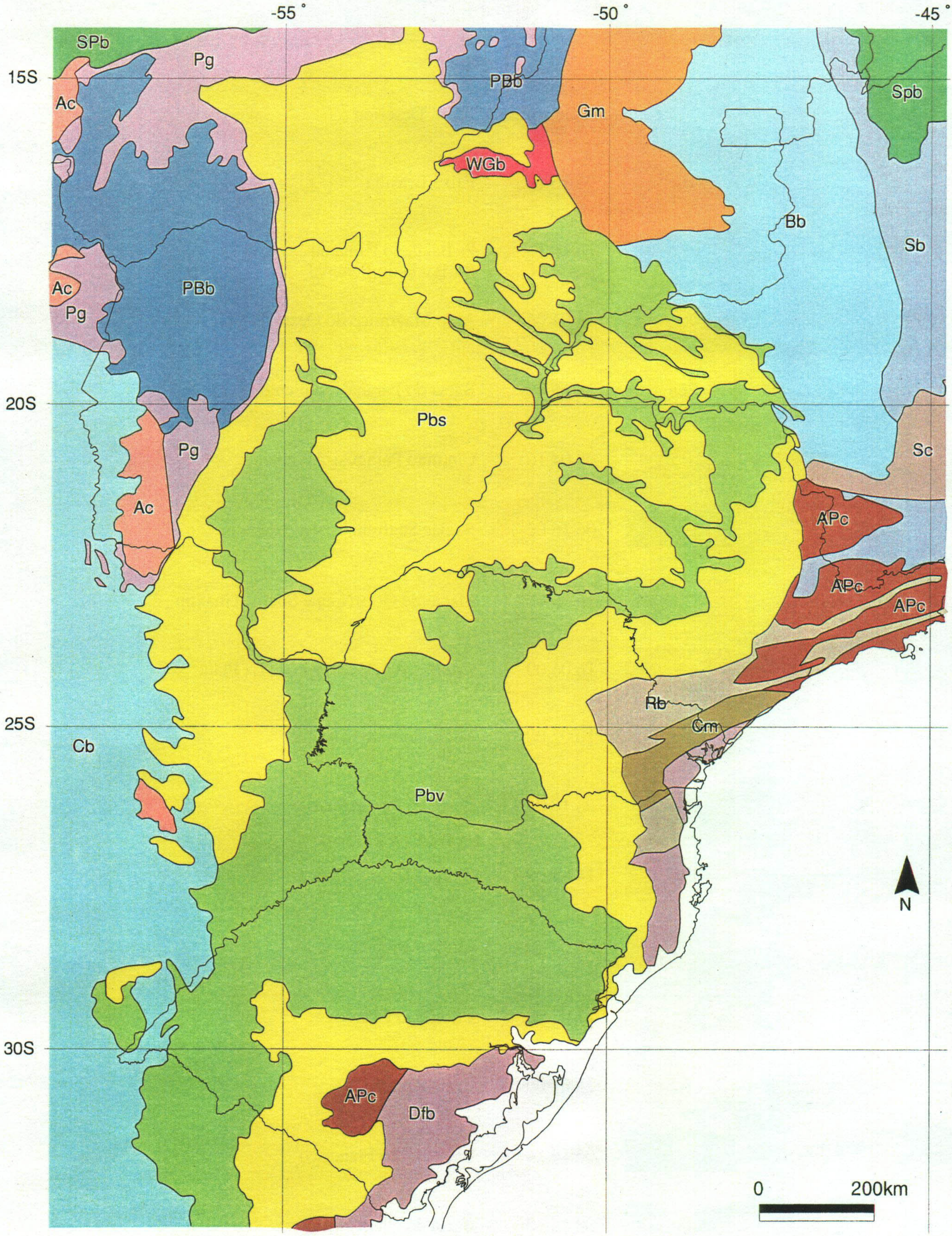

Fig. II-1-4-5 Geological and tectonic map around the Paraná basin (modified by Mantovani et al., 1991)

Convendo de cores (RGB)		Descrido
Bb	06 16 16	Faixa Brasilia
PBb	16 16 14	Pt-Bacia do Pantanal Ba-Bacia do Bananal
WGb	16 04 06	Arco Magmtico do Oeste de Goias
Pbs	16 16 02	Bacia do Parana-sedimentos
Pg	08 04 16	Cinturao Paraguai-Araguaia
SPb	06 16 02	Bacias Sanfranciscana e Parecis
Gm	16 06 02	Macio de Gois/Nappe Socrro-Guaxup
APc	16 06 00	Crtons:Luis Alves, Rio de La Plata
Cm	10 02 00	Microplaca de Curiuba
Pbv	08 16 04	Bacia do Paran-Basalto
Dfb	14 08 08	Cinturo Dom Feliciano
Rb	14 06 00	Cinturo Ribeira
Sc	12 02 00	Crton Sao Francisco
Ac	14 04 00	Crton Amaznico
Sb	06 14 14	Bacia do So Francisco
Cb	08 16 10	Bacia do Chaco

Goias Massif: The massif is composed of granitic rocks and green rocks of the Archean, and orthogneiss of the early Proterozoic (780-800 Ma). This Massif was affected by metamorphism of the Brazilian-Pan African orogenic movement. Mafic and ultramafic rocks intruded into granitic rocks and orthogneiss in the eastern margin of the Massif.

Dom Feliciano Belt: The belt is located in the direction of ENE-WSW in the eastern margin of the Paraná basin. It is composed of granite, migmatite, orthogneiss and granulite. It is also distributed in the southeastern side of the Rio de La Plata craton and Ribeira Belt.

Ribeira Belt: It is located in the eastern margin of the Paraná basin and is exposed in the direction of ENE-WSW. It is composed of volcanic rocks, sedimentary rocks, orthogneiss, amphibolites, mafic and ultramafic rocks, and granulites of the Proterozoic to the Paleozoic. The belt thrusts up the Curitiba microplate which is distributed in the SE direction.

Rio de la Plata-Luis Alves Craton: The Rio de La Plata craton is exposed in the SW-NE direction in the southern to eastern margin of the Paraná basin. The Luis Alves craton, which is located in the southeast of Paraná Province, is composed of granulites and the Campo Alegre Formation. The granulite was affected by metamorphism in the Proterozoic. The Campo Alegre Formation includes molasse sediments and is composed of volcanic rocks and sedimentary rocks (580-500 Ma).

(2) Arch and Lineament

The main tectonic directions in the basement of the Paraná basin are the NE-SW and NW-SE directions. The tectonic directions of E-W and N-S partly also observed (Fig. II-1-4-4, Fig. II-1-4-5, II-1-4-6). The tectonic direction of NE-SW is dominant in thrust and folding of the late Proterozoic in the basement. The tectonic direction of NE-SW corresponds to the direction of Brazilian-Pan African orogenic movement. The tectonic zone in the direction of NE-SW acted again in the Phanerozoic as the fractured zone within the crust in the compressive stress field.

In the late Ordovician, the first subsidence of the basin occurred, being accompanied with lateral fault in the direction of NE-SW. The re-movement of old lineament affected the depocenter and drainage of the basin and finally controlled the sedimentation of the basin. There are almost no dykes and sills along fractures in the direction of NE-SW on the ground surface.

Another dominant tectonic direction of the Paraná basin was brought about due to the uplifting movement from the Devonian to the late Jurassic and the rifting of the South Atlantic Ocean in the Cretaceous. The lateral strike faults (shear fracture) within and in the margin of the basin coincide with the direction of NW-SE. Many tholeiitic dolerite dikes are filled up in the fractures of the NW-SE direction. The tectonic movement in the NW-SE direction also formed the Ponta Grossa arch, Campo Grande arch and Rio Grande arch, Guapiara fault, Rio