Indications of an Underground "River" beneath the Amazon River: Inferences from Results of Geothermal Studies

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Motivation

- ☺ Fluvial systems of the Amazon basins constitute one of the largest drainage systems on the surface of the Earth. The characteristics of this surface discharge system have been the object of a large number of investigations over the last several decades (Jaccon and Cudo, 1987; Guimarães et al., 1993; Molinier et al., 1994).

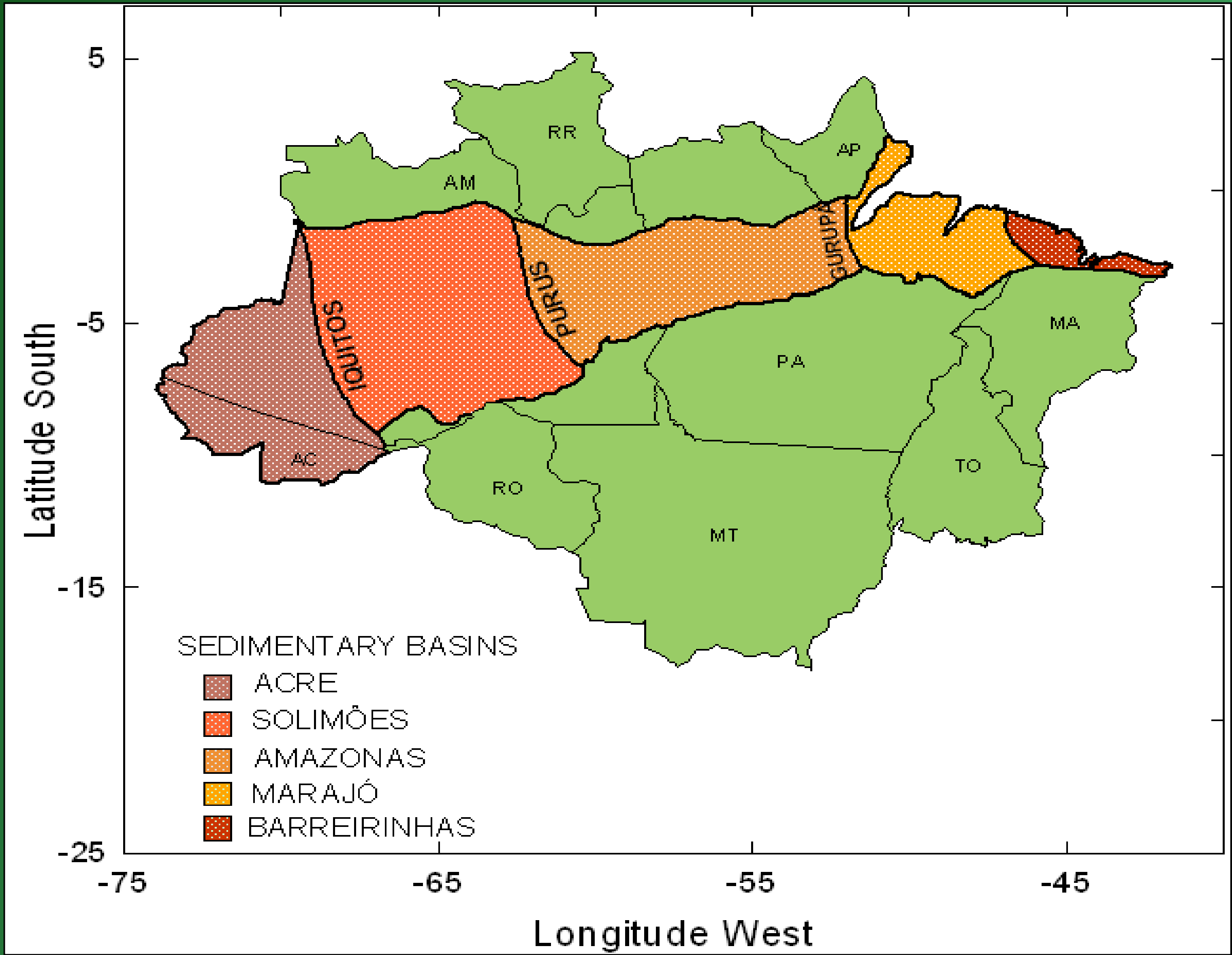
- ☺ Nevertheless relatively few investigations have been carried out in understanding the characteristics of recharge and discharge of groundwater and conditions of subsurface flow in this region.

- ☺ Most of the studies of groundwater hydrology in the Amazon region has been carried out as part of investigations of subsurface flow systems on local scales, there being very few evaluations on regional scales.

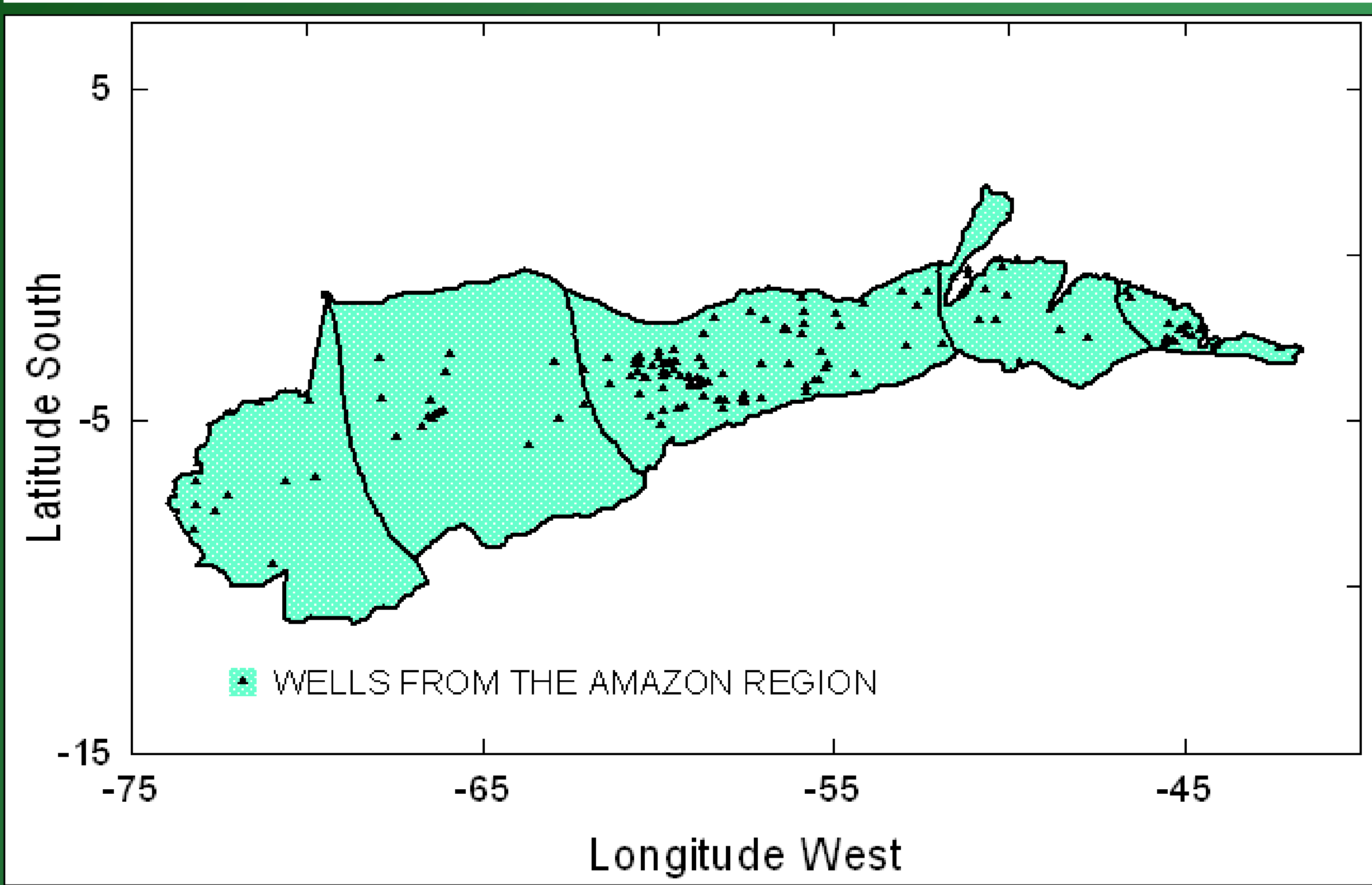
Objective

- ☺ In this context the main objective of the present work is to examine in the characteristics of geothermal data acquired in deep boreholes and wells and its use for determining regional scale subsurface fluid flows of groundwater in the Amazon region.

Characteristics of the Study Area



Database of the present work



Authorship: Pimentel and Hamza (2010)

- 241 localities in the Amazon region
- 185 are located within the regions of sedimentary basins
- 56 localities are situated outside areas of sedimentary basins

Methodology

- ☺ The principle of geothermal method for study of groundwater flows can be understood by considering the role of advection heat transfer on the conductive regime of subsurface layers.

- ☺ Studies on the use of geothermal methods for obtaining information on groundwater flows were carried out by Cartwright (1970), Mansure and Reiter (1979), Hamza (1982), Hamza et al. (1986), Yamabe and Hamza (1996) and Assumpção et al. (2010).

Conduction – Advection Equation

- ☺ Under steady state conditions the equation for simultaneous heat transfer by conduction and advection in a porous and permeable medium of homogeneous thermal properties is (Stallman, 1963):

$$\lambda_s\left[\frac{\partial^2 T}{\partial x^2}+\frac{\partial^2 T}{\partial y^2}+\frac{\partial^2 T}{\partial z^2}\right]-\rho_f C_f\left[\frac{\partial(v_x T)}{\partial x}+\frac{\partial(v_y T)}{\partial y}+\frac{\partial(v_z T)}{\partial z}\right]=0$$

Where

T – Temperature at the position determined by the coordinates (x, y and z);

λ_S – Thermal conductivity of the solid medium;

$\rho_f C_f$ – Thermal capacity, of the fluids in the pore space;

v_x, v_y and v_z – Velocity components of fluids in the directions x, y e z respectively.

Solution for 1D - Case

☺ In the case one dimensional flow of heat and fluids the equation may be simplified as:

$$\lambda_s \left[\frac{\partial^2 T}{\partial z^2} \right] = \rho_f C_f v_z \left[\frac{\partial T}{\partial z} \right]$$

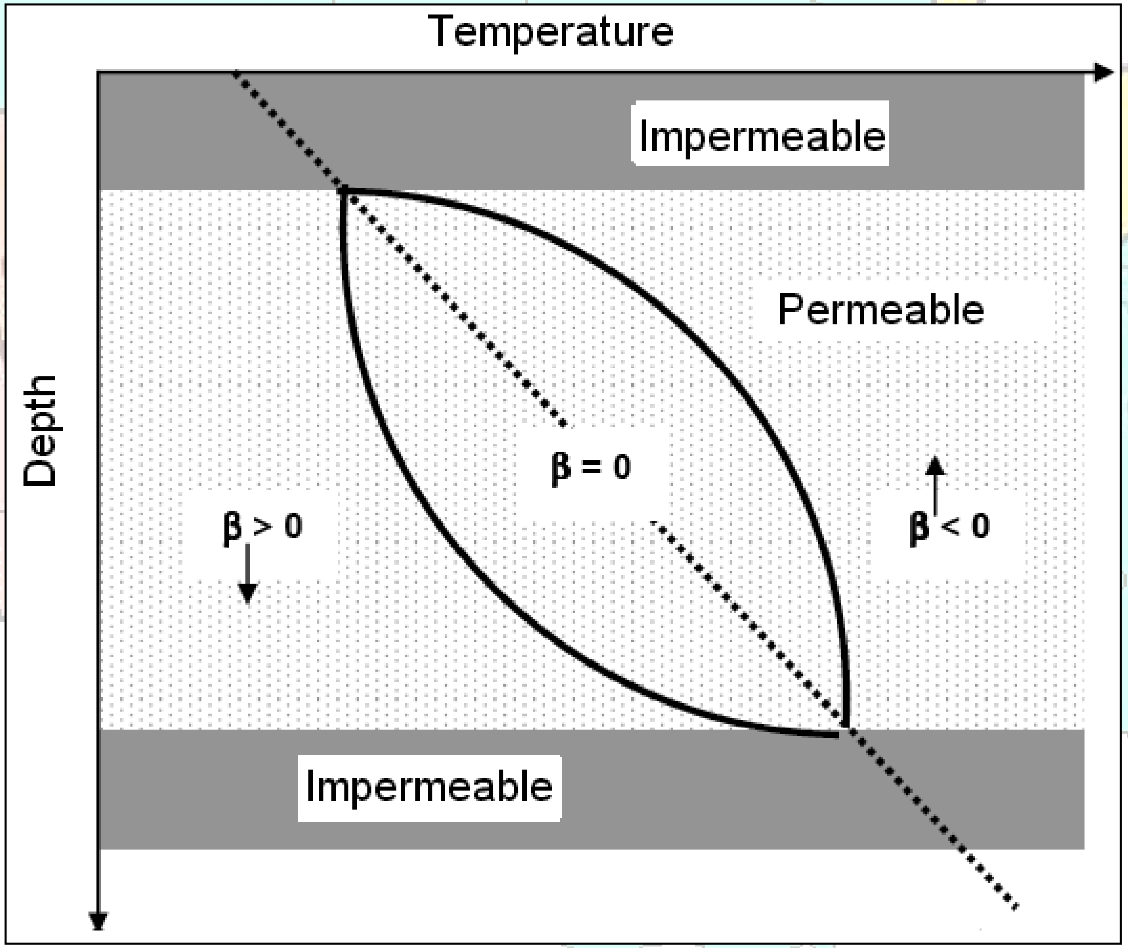
The solution of this equation for the boundary conditions that T = T_0 at z = 0 and T = T_L at z = L is (Bredehoeft and Papadopulos, 1965):

$$\frac{T_z - T_0}{T_L - T_0} = \frac{[\exp(\beta z / L) - 1]}{[\exp(\beta) - 1]}$$

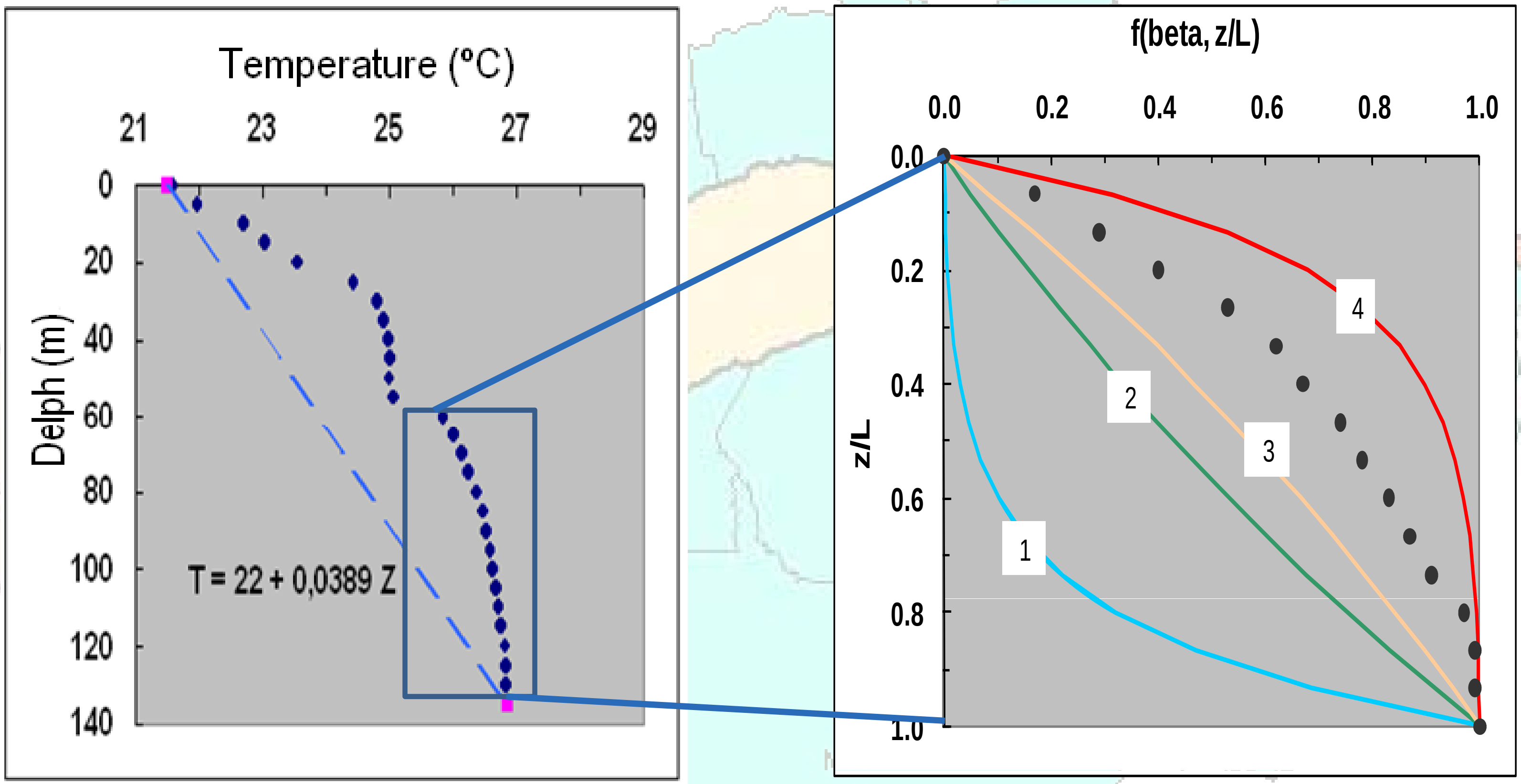
where

$$\beta = \frac{\rho_f C_f v_z L}{\lambda_s}$$

Schematic illustration of the effects of groundwater flows in temperature profiles.

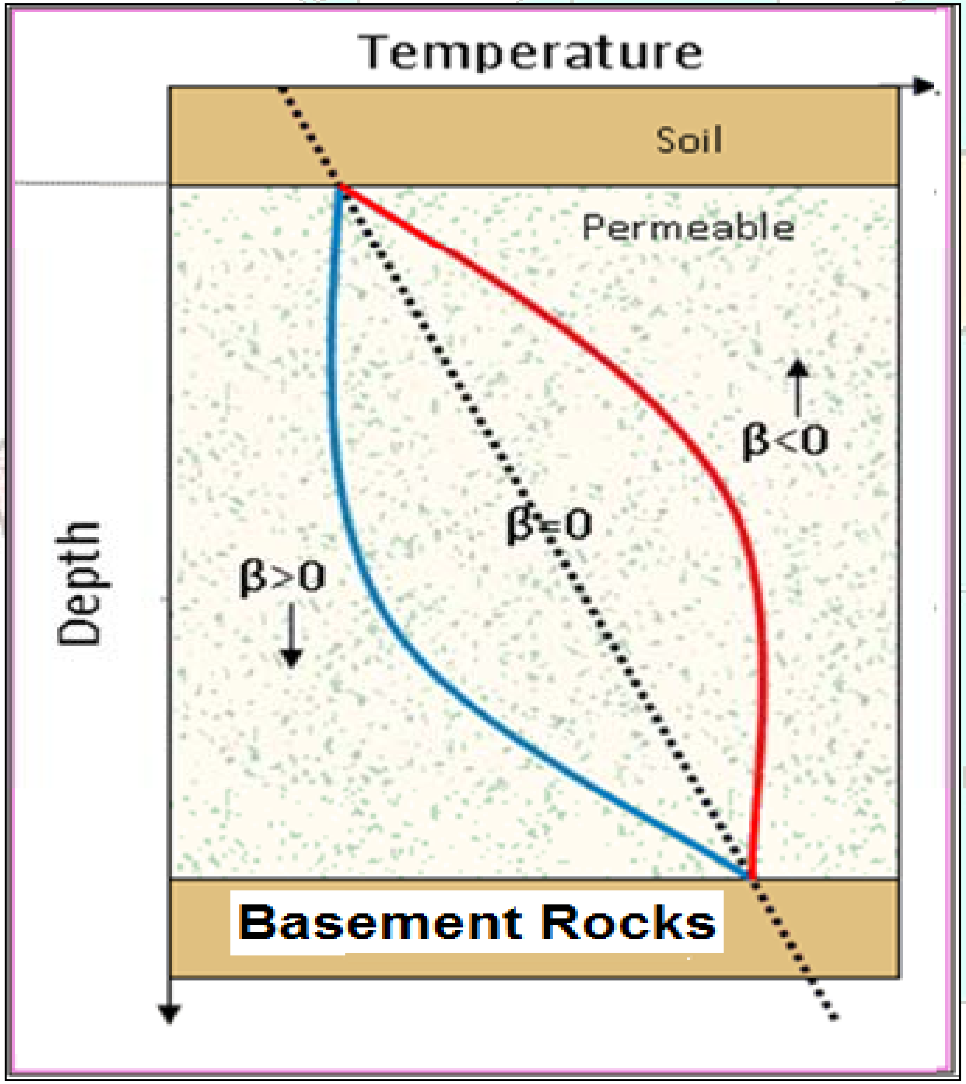


☺ In the conventional approach theoretical curves are fit to a set of results of a selected depth interval in temperature logs, as in the figure below:



☺ The implicit assumption here is that the flow is limited to the selected depth interval. This practice is unsuitable for studies of deep flow in sedimentary basins, when the lower limit for flow is different from that of temperature.

Modified Scheme for temperature distribution in the presence of groundwater flow in sedimentary basins.



Assumptions

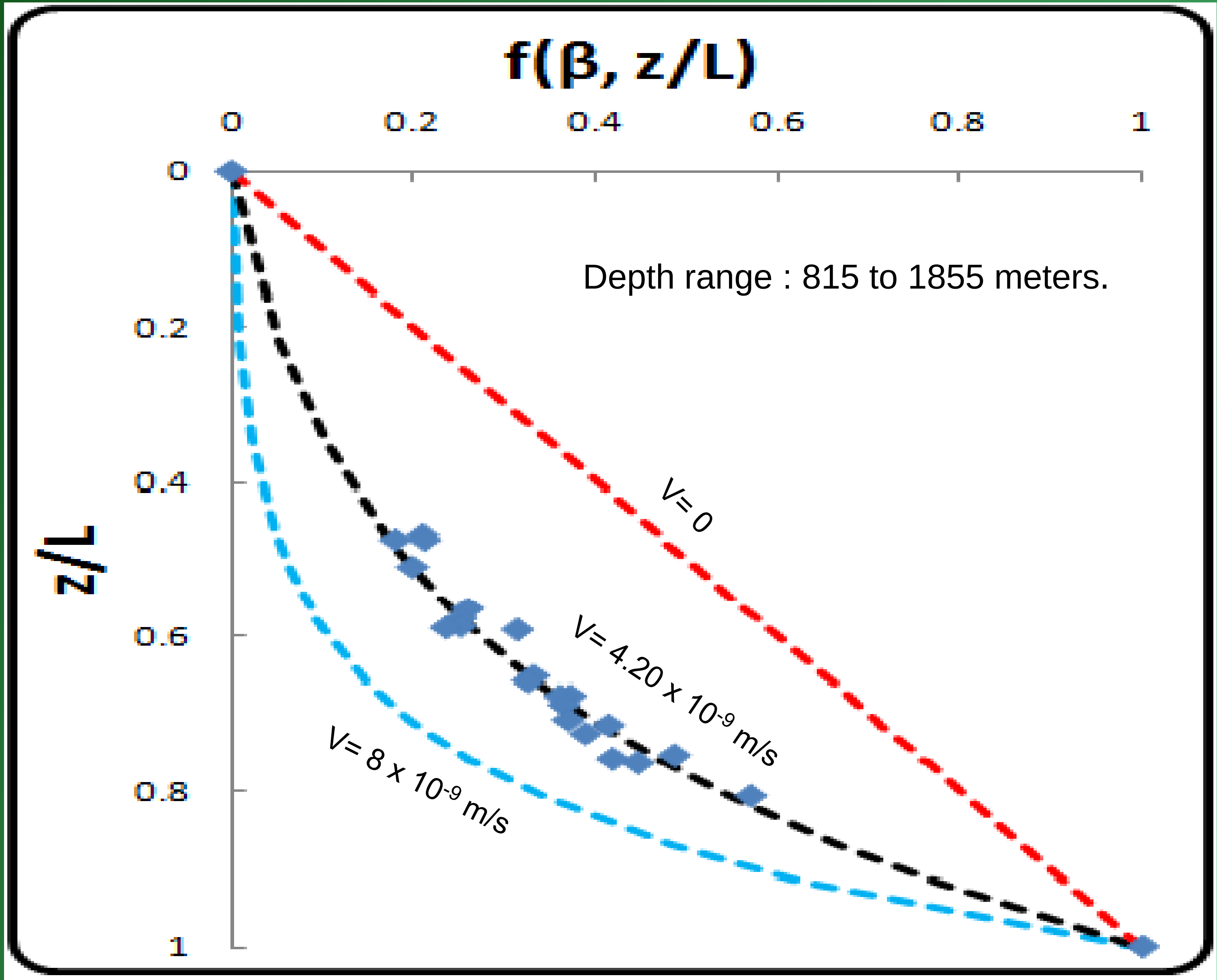
- Curvatures in Temperature profiles are mainly due to advection;
- Groundwater flows extend all the way to the basement.
- Lower limit is set on the basis of data on porosities of main rock types.

Results

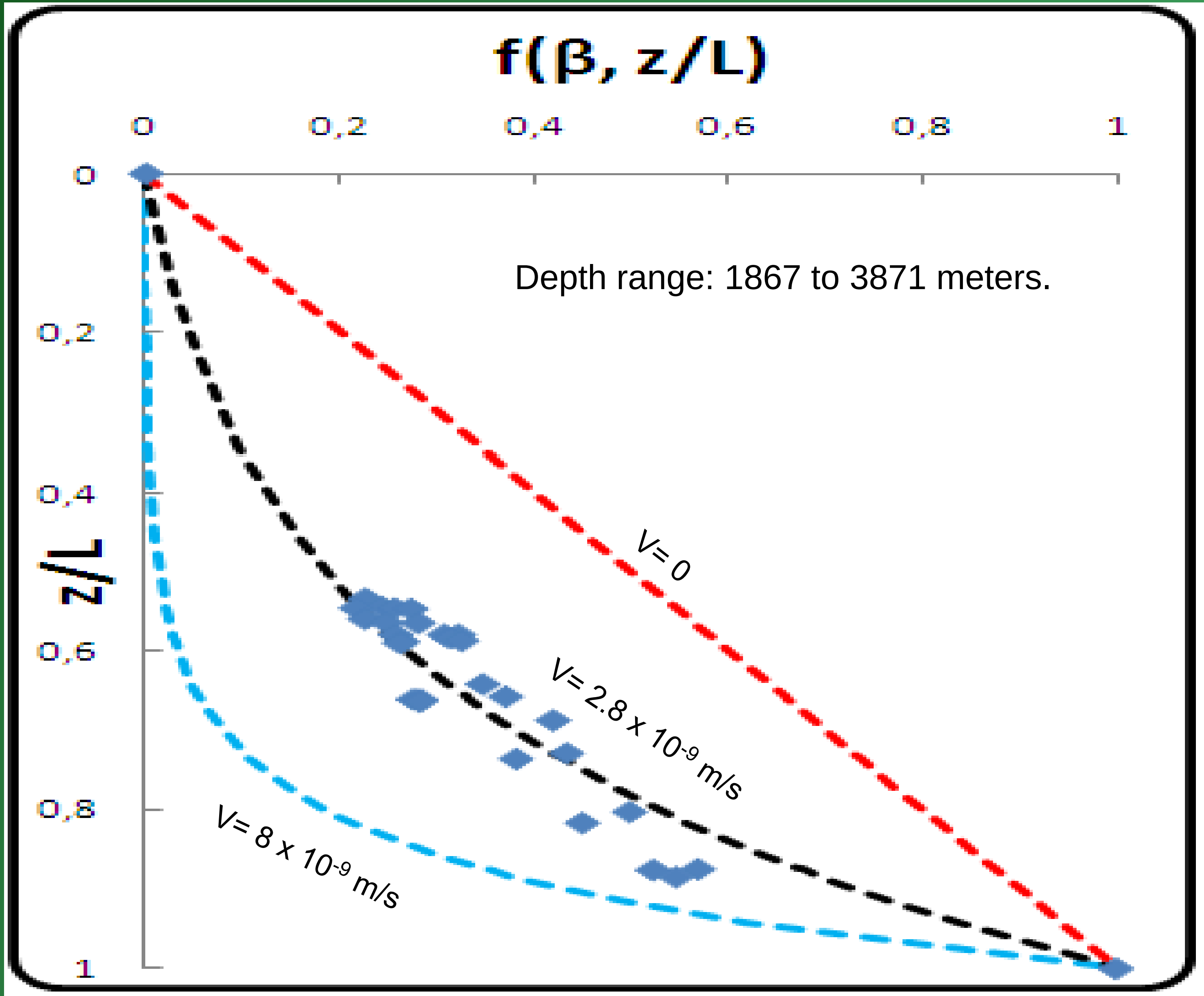
☺ The results obtained reveal that concave shaped curvatures in temperature distributions in the Amazon basins are typical of regional scale down flow of groundwater.

☺ Such grouping was done in view of the indications that flow systems in the upper parts of sedimentary basins have velocities different from those at lower levels.

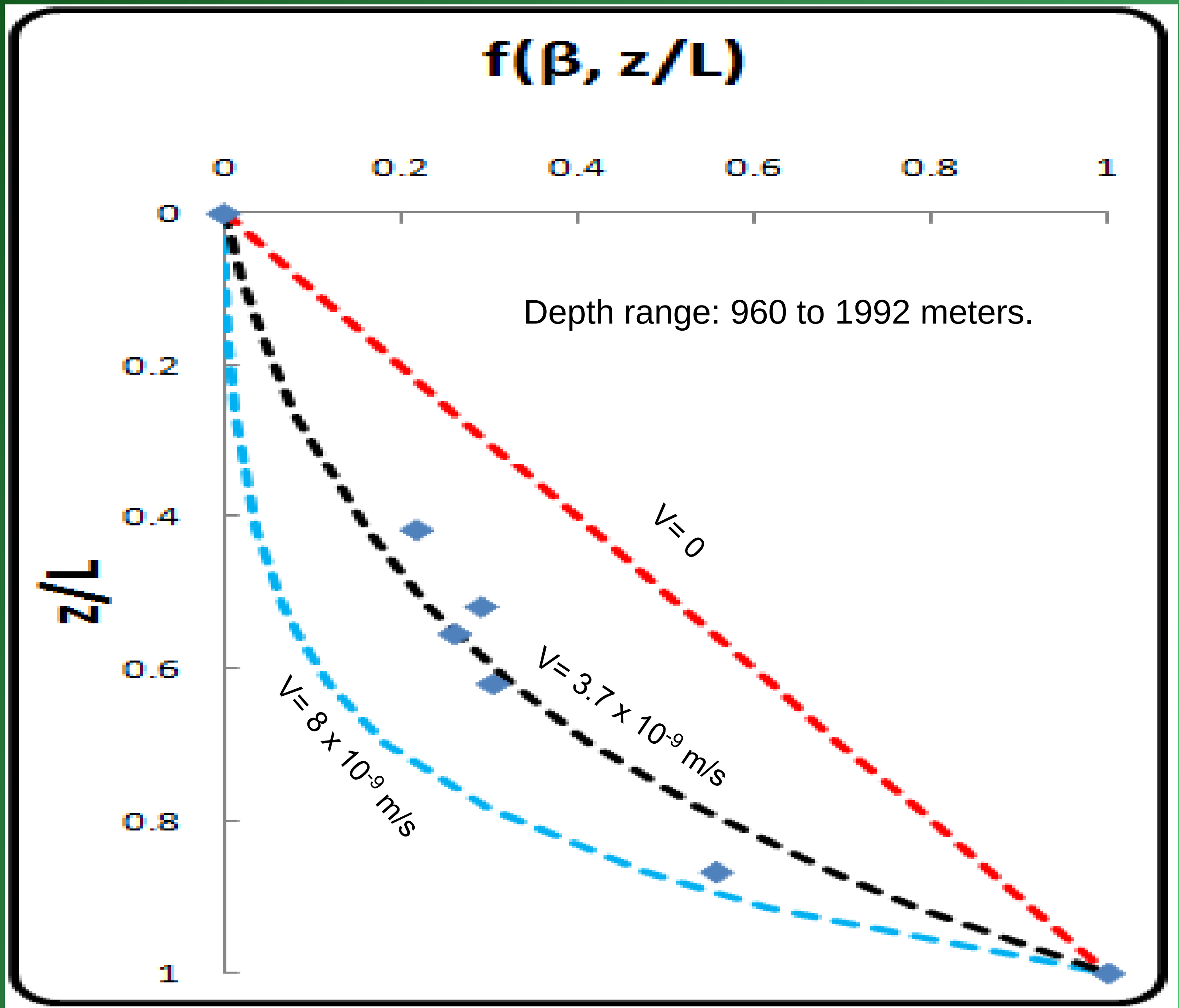
Amazonas Basin – Upper flow system



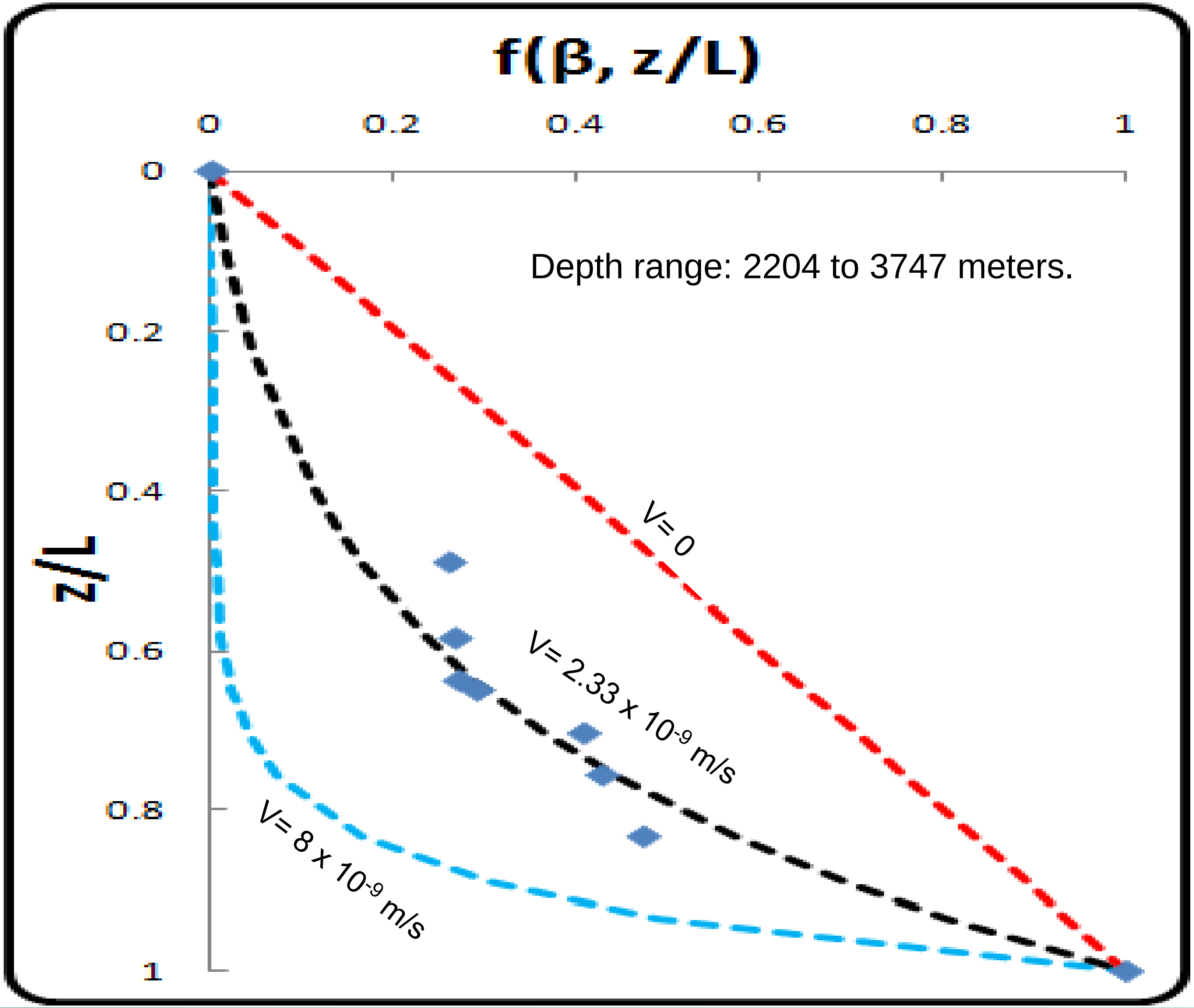
Amazonas Basin – Deeper flow system



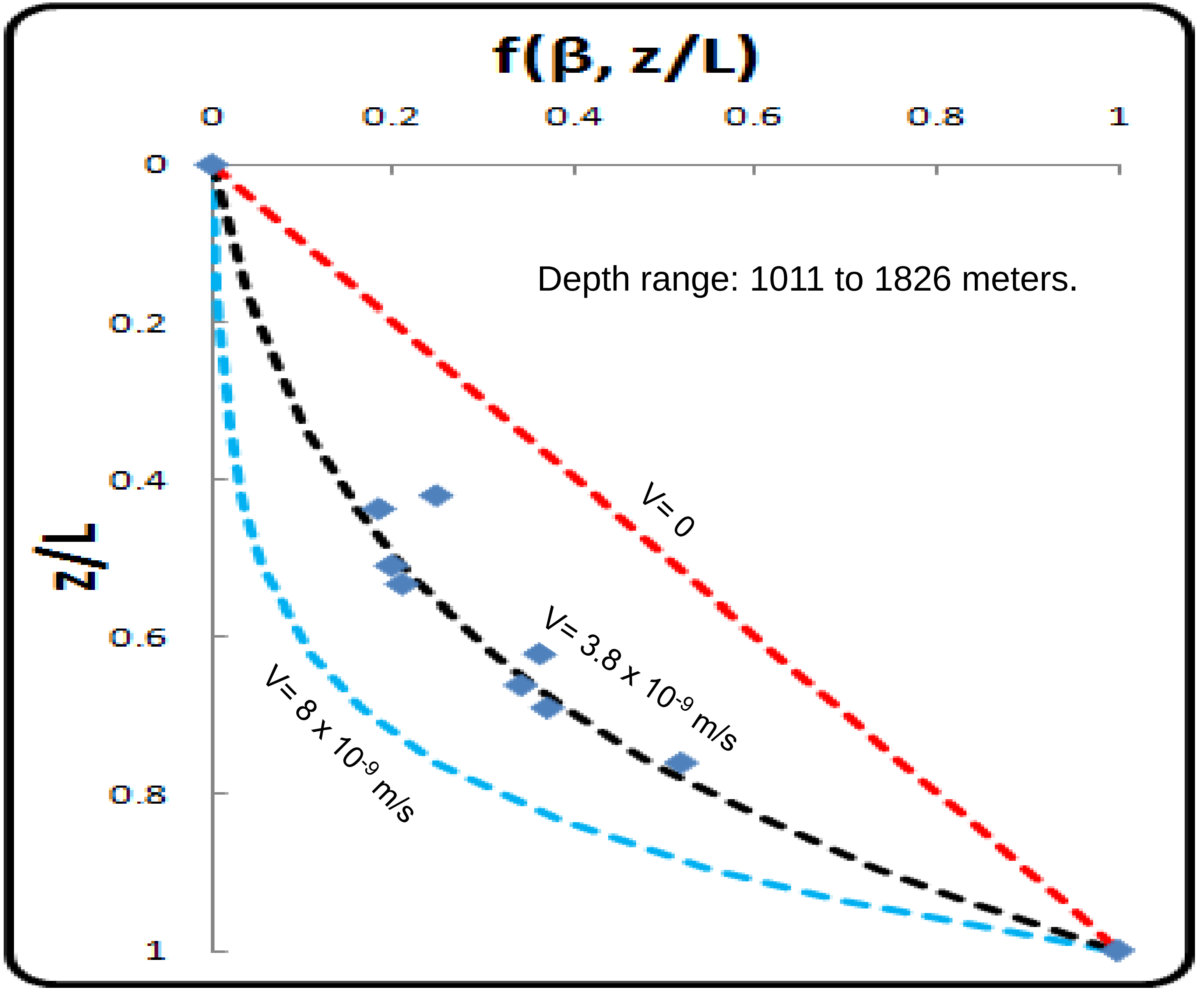
Acre Basin: Upper flow system



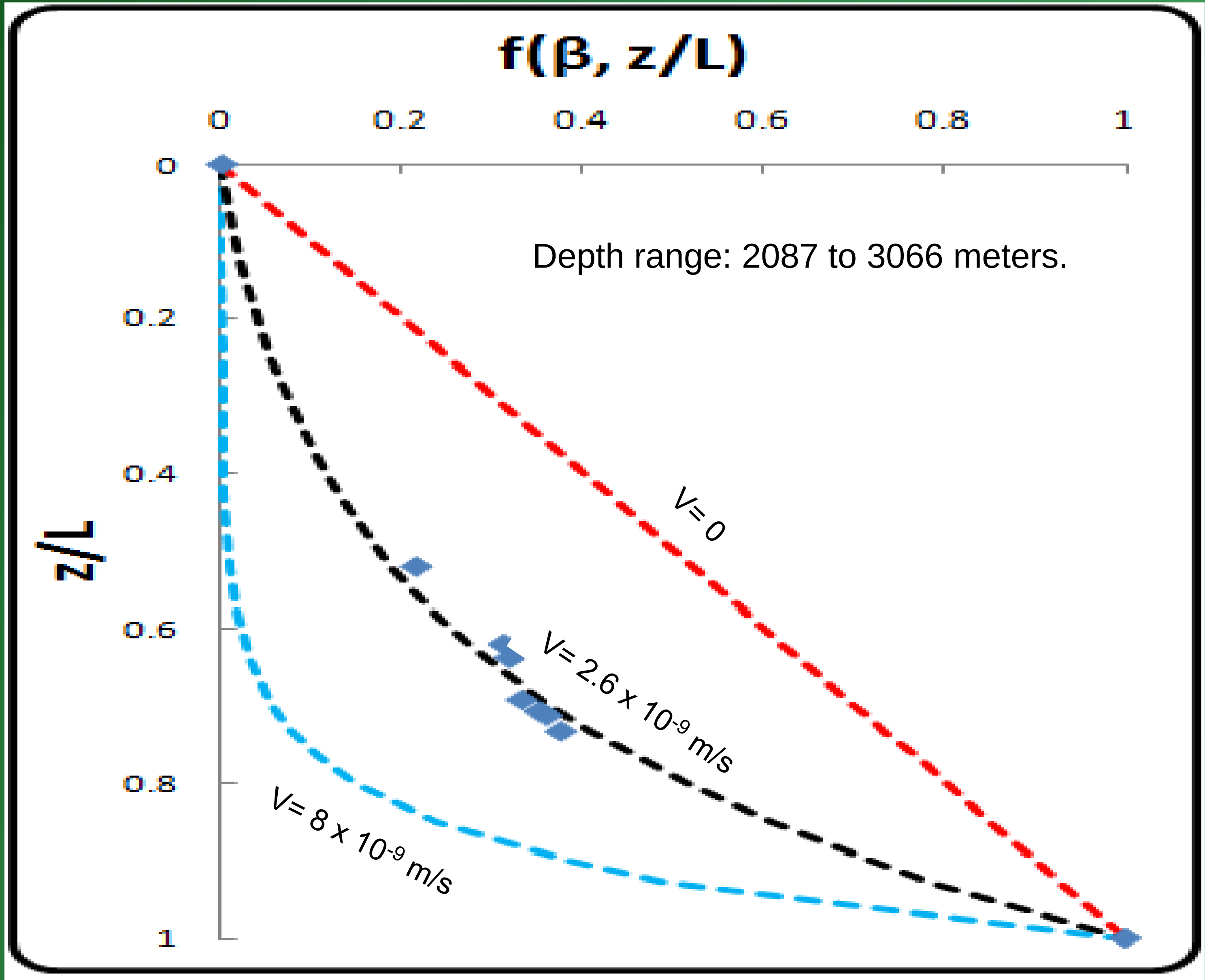
Acre Basin – Deeper flow system



Solimões Basin – Upper flow system



Solimões Basin – Deeper flow system



Estimates of the Flow Rates

Basin / Region	Mean Velocity (m/s)	Area (m^2)	Flow Rate (m^3/s)
Acre	3.02E-09	1,50E+11	452.25
Solimões	3.20E-09	4,40E+11	1408.00
Amazonas	3.50E-09	5,00E+11	1750.00
Marajó	2.45E-09	5,30E+10	129.85
Barreirinhas	3.50E-09	4,60E+10	161.00
Total			3901.10

Characteristics of subsurface flows in the Amazon basins

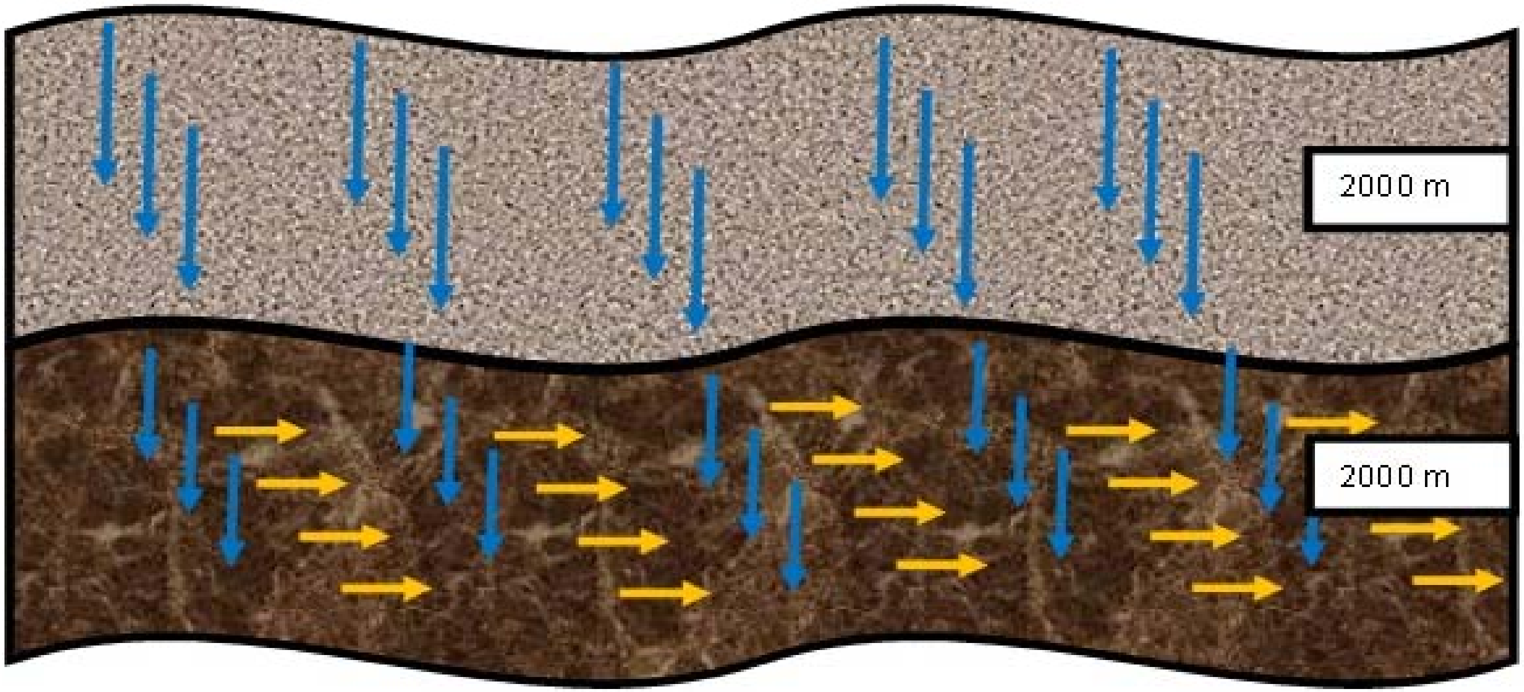
☺ Regional hydraulic gradient favors lateral flow from west to east (i.e.: from foot hills of Andean mountains to the Atlantic ocean.)

☺ Porosity and permeability are large in the upper rock formations relative to the lower ones.

Inferences

☺The upper parts of geologic formations in Amazon basins are characterized by down flow of groundwater.

☺The lower parts of geologic formations in Amazon basins are characterized by both down and lateral (in the direction of west to east) flows of groundwater.



Comparison of Flow Systems in the Amazon Basins

Description	Surface Drainage (Amazon River)	Subsurface Flow (Hamza River)
Length (km)	≈ 6110	≈ 6000
Breadth (km)	≈ 1 - 100	≈ 200 - 400
Flow Velocity (m/s)	0.05 - 5	10^{-8} to 10^{-9}
Flow Rate (m^3/s)	≈ 133.000	≈ 3900

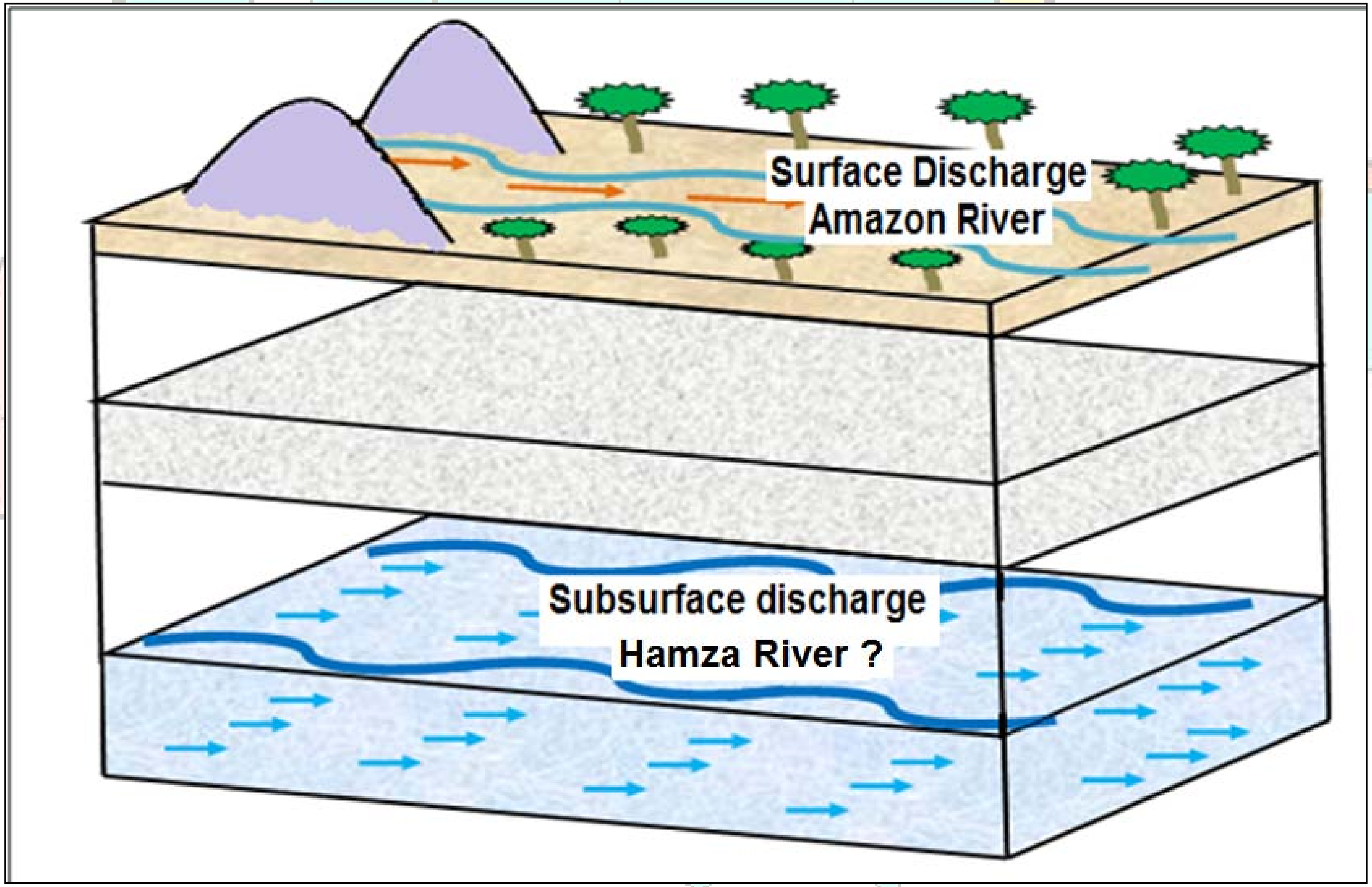
Conclusions

☺ Analysis of the relations between dimensionless values of BHT and depth in oil wells has allowed estimates of the vertical recharge velocities for groundwater flows in five distinct sedimentary basins of the Amazon region.

☺ At shallow depths of less than 2000 m the velocities are systematically high compared to those for deeper depth levels.

☺ Relatively high velocities of 3.5×10^{-9} m/s are observed in the Amazonas and Barreirinhas basins. The lowest value of 2.4×10^{-9} m/s is found for the Marajó basin. Intermediate values of velocities are found for Acre and Solimões basins.

☺ The observed vertical recharge velocities are indicative of an extensive subsurface lateral flow system in the direction of west to east in the Amazon region.



Schematic Representation of the subsurface Flow system

☺ The overall subsurface lateral discharge rate estimated for the Amazon region is 3900 m^3/s.

☺ For comparison purposes we note that this value is much higher than the surface discharge (≈ 2850 m^3/s) of the São Francisco river system in the eastern parts of Brazil.

☺ We conclude that the impacts of such lateral flow patterns must be included in assessment of overall hydrological systems for the Amazon region.

Acknowledgments

Ufam (Universidade Federal do Amazonas)

Fapeam (Fundação de Amparo à Pesquisa do Estado do Amazonas)

ON (Observatório Nacional-RJ)

Ao Grupo de Geotermia do ON

Thanks !!!