Geophys. J. Int. 143,

Permanent water level drop associated with the Spitak Earthquake: observations at Lisi Borehole (Republic of Georgia) and modelling

Geosciences Rennes, CNRS, Rennes, France
Gruzgeologia, Tbilissi, Republic of Georgia
Institute of Geophysics, Georgian Academy of Sciences, Tbilissi, Republic of Georgia

SUMMARY

Key words:

1 INTRODUCTION

et al.

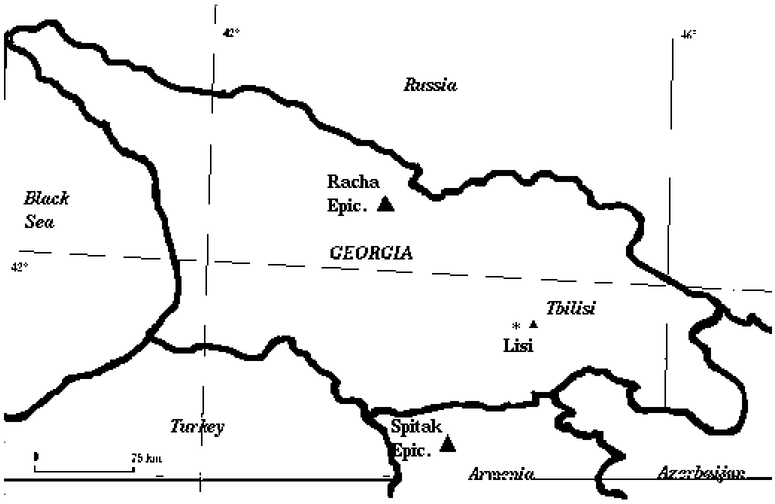


Figure 1.

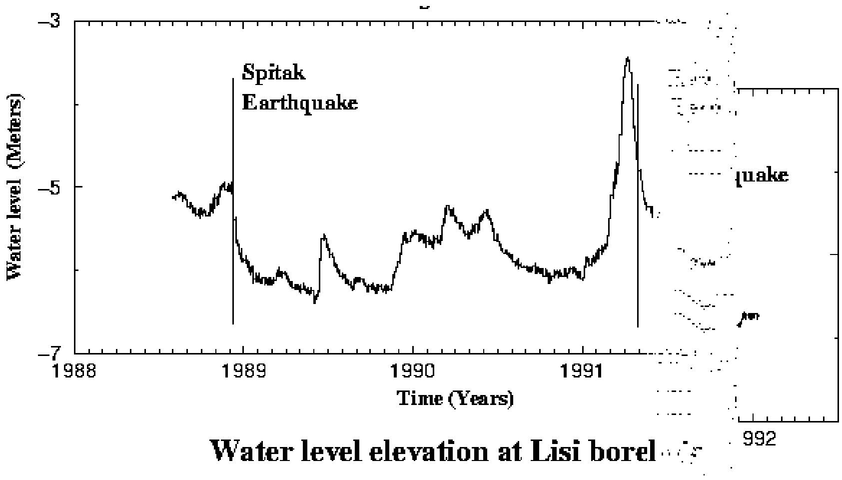


Figure 2.

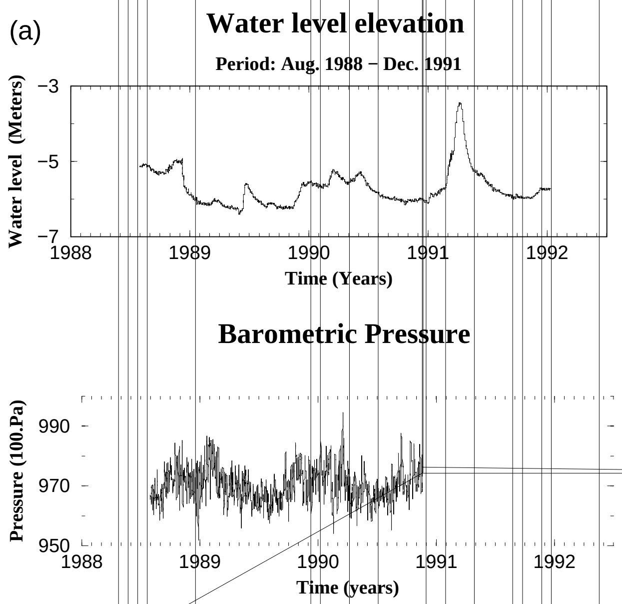


Table 1. [illegible]

[illegible]	[illegible]	[illegible]	[illegible]
	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]
	[illegible]	[illegible]	[illegible]
	[illegible]	[illegible]	[illegible]
	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]
	[illegible]	[illegible]	[illegible]
	[illegible]	[illegible]	[illegible]

[illegible] *et al.* [illegible]

[illegible] $\approx$ [illegible] $\approx$ [illegible]

[illegible]

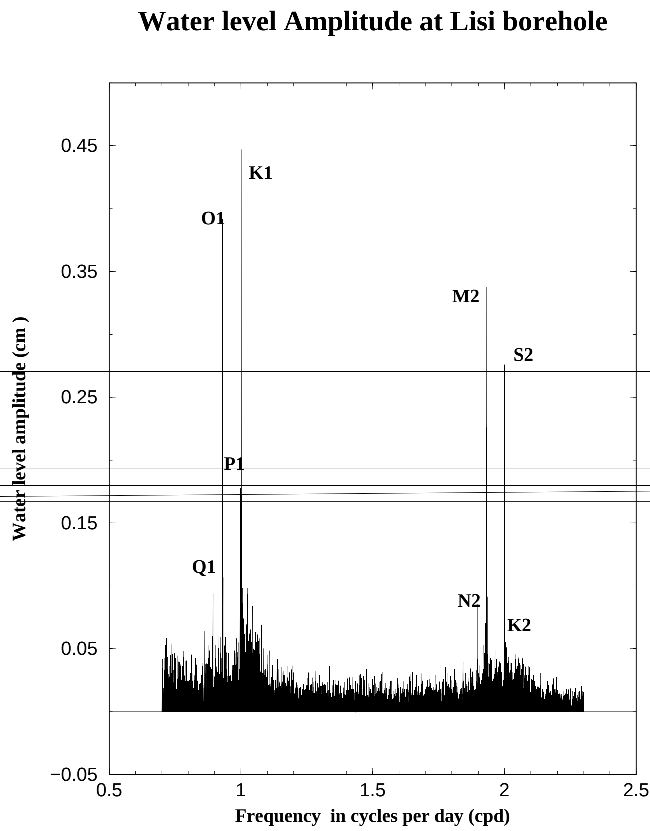
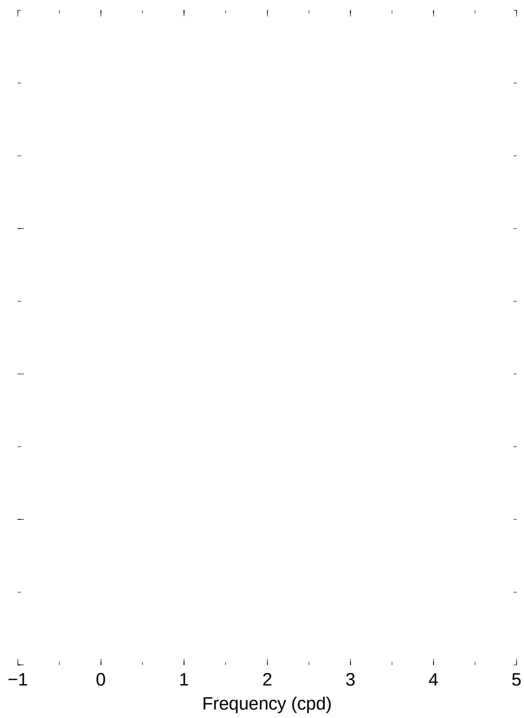


Figure 4. [illegible]

2 DATA PROCESSING

2.1 Tidal analysis

[illegible]



2.2 'Slug test' analysis

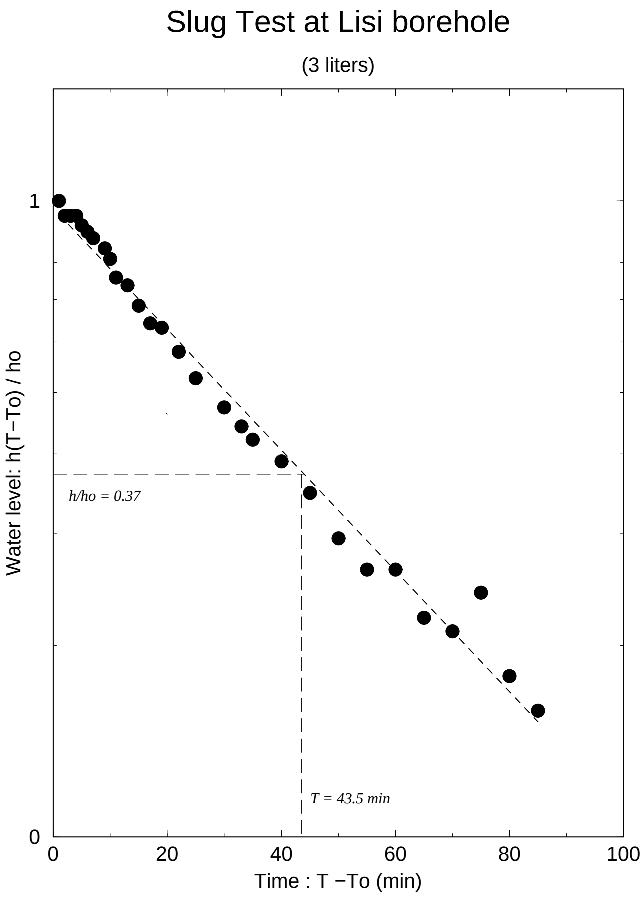


Figure 6. [illegible]

[illegible] *et al* [illegible] K [illegible] S_s [illegible]

2.3 Barometric analysis

[illegible]

$$E_B = \rho g h / P_a \,,$$

[illegible] h [illegible] P_a [illegible] P [illegible] E_B [illegible]

[illegible]

$$E_B(\omega) = \frac{BB(\omega)TW(\omega) - TB(\omega)BW(\omega)}{BB(\omega)TT(\omega) - BT(\omega)TB(\omega)} \,,$$

[illegible] $XY(\omega)$ [illegible] $X(t)$ [illegible] $Y(t)$ [illegible] $B(t)$, $T(t)$ [illegible] $W(t)$ [illegible] $BB(\omega)$ [illegible] $BW(\omega)$ [illegible]

[illegible]

$$E_B = -(1-\alpha)(1 - A\exp\{-[i\omega(z_b - z_w)^2/c]^{1/2}\}) \,,$$

[illegible] α [illegible] A [illegible] $i\omega$ [illegible] c [illegible]

[illegible] α [illegible] c [illegible]

[illegible] $\alpha =$ [illegible] $\pm$ [illegible] $c =$ [illegible] $\pm$ [illegible] $S_s =$ [illegible] $K_{[illegible]} =$ [illegible]

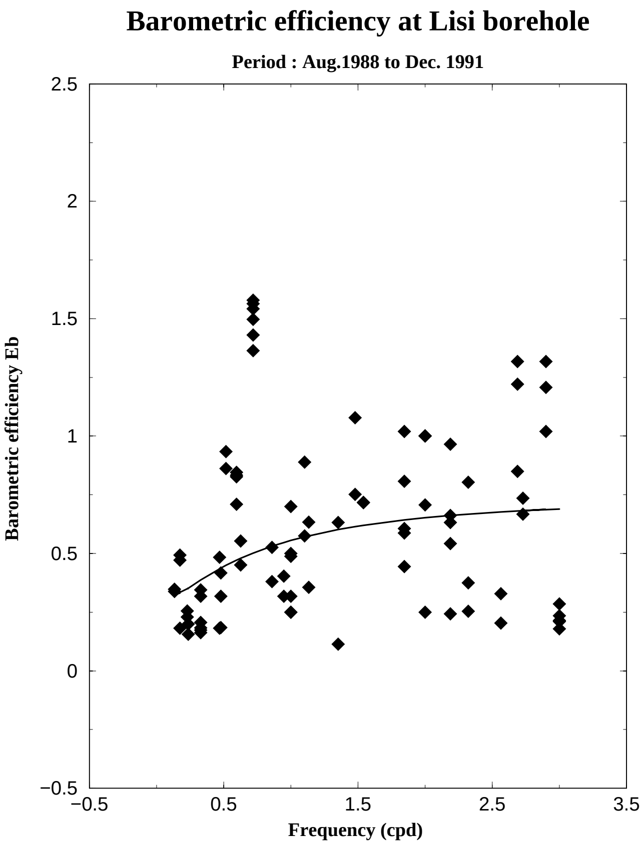


Figure 7. [illegible]

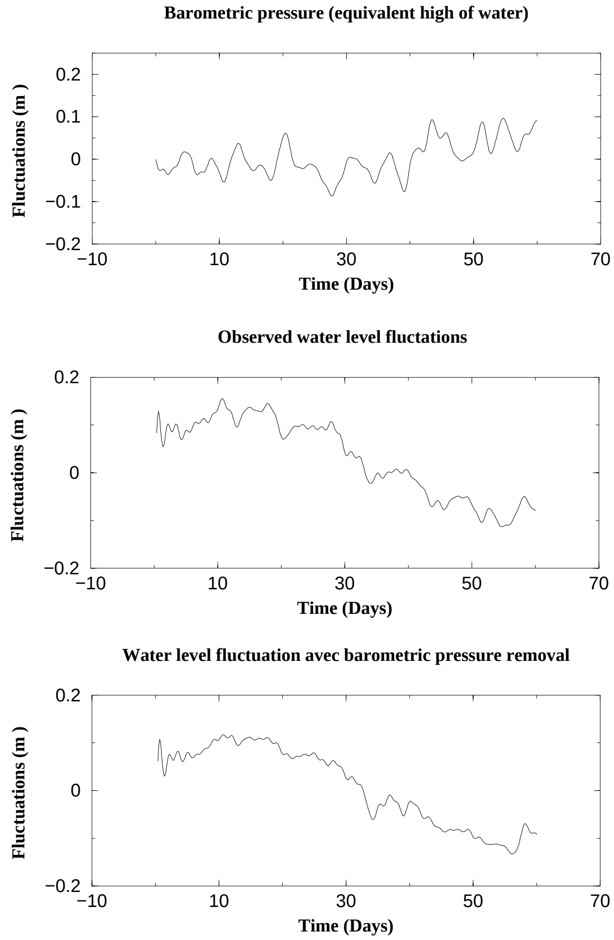


Figure 8. [illegible]

[illegible] *a posteriori*[illegible]

2.4 Pluviometric analysis

[illegible]

$$S = P - E - T\,, \qquad \text{([illegible])}$$

[illegible] S [illegible] P [illegible] E [illegible] T [illegible] T [illegible] ΔW[illegible]Δt[illegible] W [illegible] t [illegible]

[illegible] PE [illegible] PE [illegible] WATBUG [illegible] WATBUG [illegible] P [illegible] PE[illegible]

[illegible] S [illegible]

$$W_{t+[illegible]} = W_t + (P - PE)W_t [illegible] W_*, \quad ([illegible])$$

[illegible] $W_{[illegible]}$ [illegible] t [illegible] $W_{[illegible]}$ [illegible] $W_{[illegible]}$ [illegible] W_t [illegible] $W_{[illegible]}$ [illegible]

[illegible] P [illegible] PE [illegible]:

$$W_{t+[illegible]} = W_t + (P - PE). \quad ([illegible])$$

[illegible] $W_{t+[illegible]} > W_{[illegible]}$ [illegible] $W_{t+[illegible]}$ [illegible] $W_{[illegible]}$ [illegible] $W_{t+[illegible]} - W_{[illegible]}$ [illegible] $W_{[illegible]}$ [illegible]

[illegible] *et al.* [illegible]

[illegible]

a priori

$$u(t) = u[illegible] - \exp(-t/t_e),$$

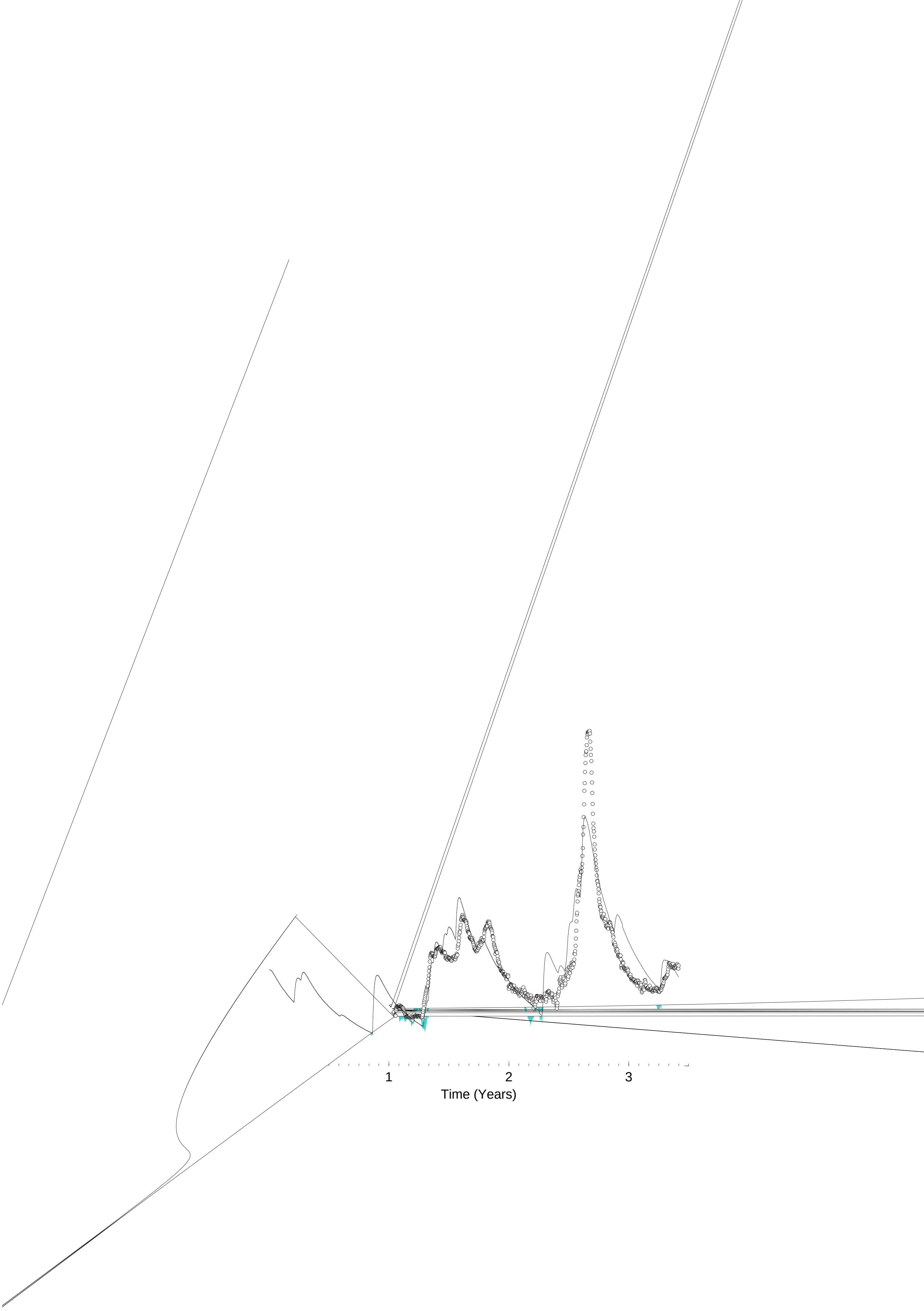
u $t = $ $t = $ $t = $ $\Delta =$ $M =$

et al.

3 MODELLING PHYSICAL PROCESSES

et al.

$\Delta h = A D^{-}$


1
2
3
Time (Years)

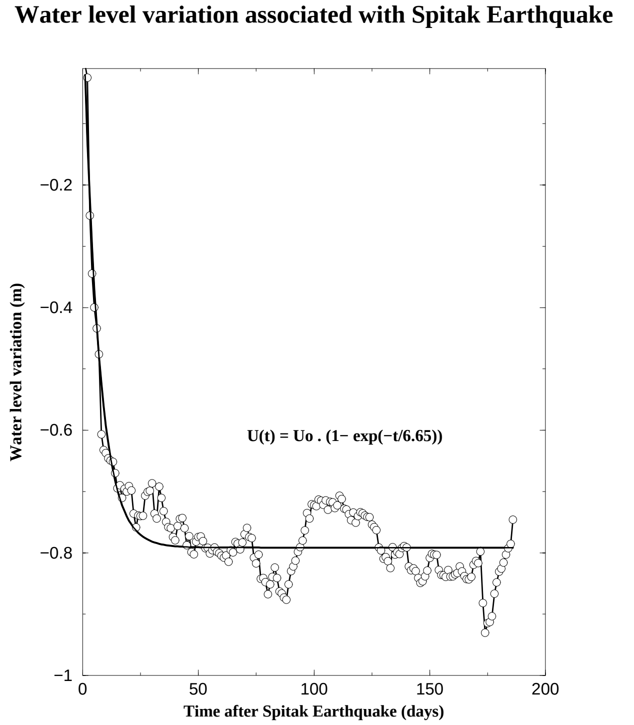


Figure 11.

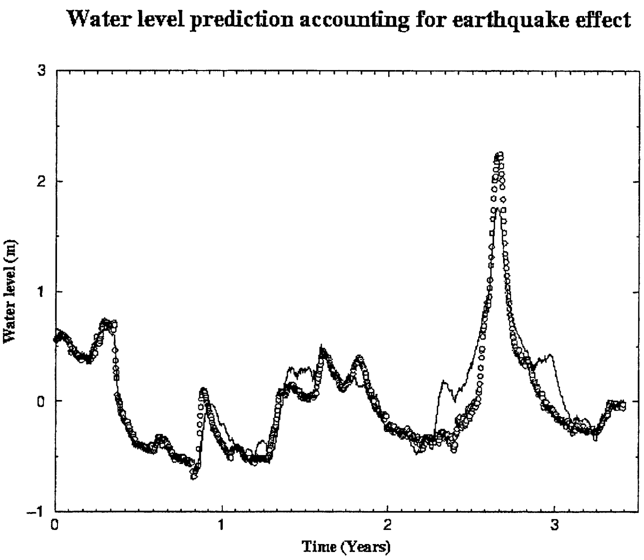


Figure 12.

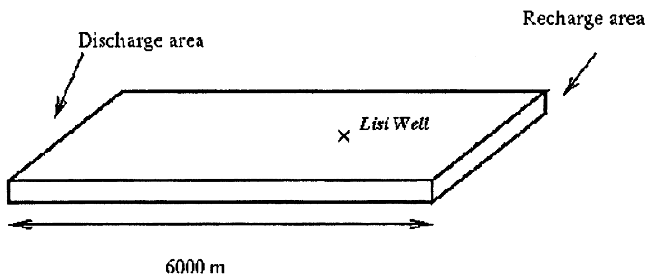


Figure 13.

$$h(x, t=\square)=(s_{\square}K)x\,,$$

3.1 Variable-permeability model

3.2 Variable-porosity model

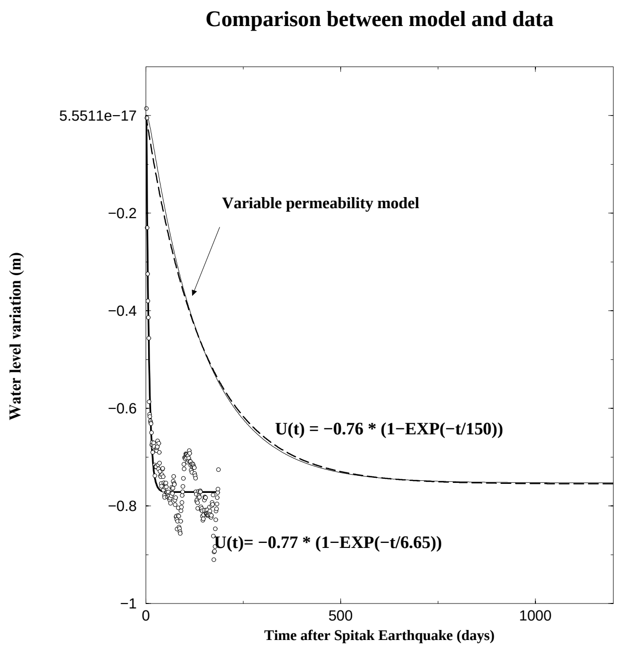


Figure 14.

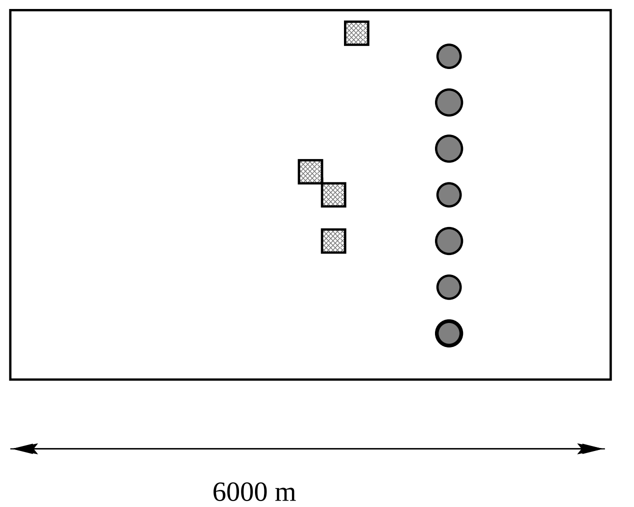
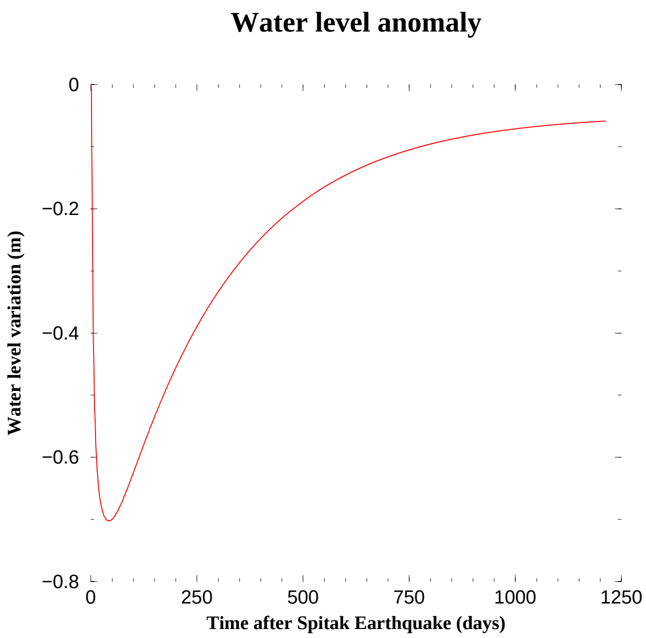


Figure 15.

3.3 Towards a mixed model



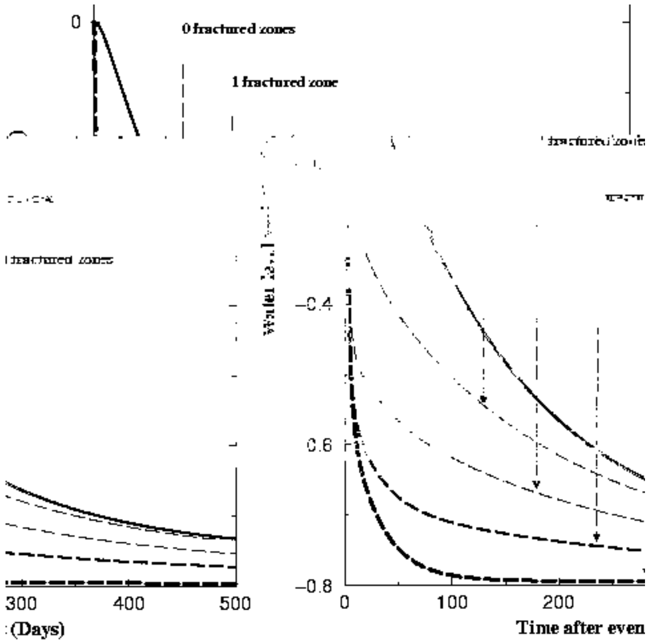


Figure 19.

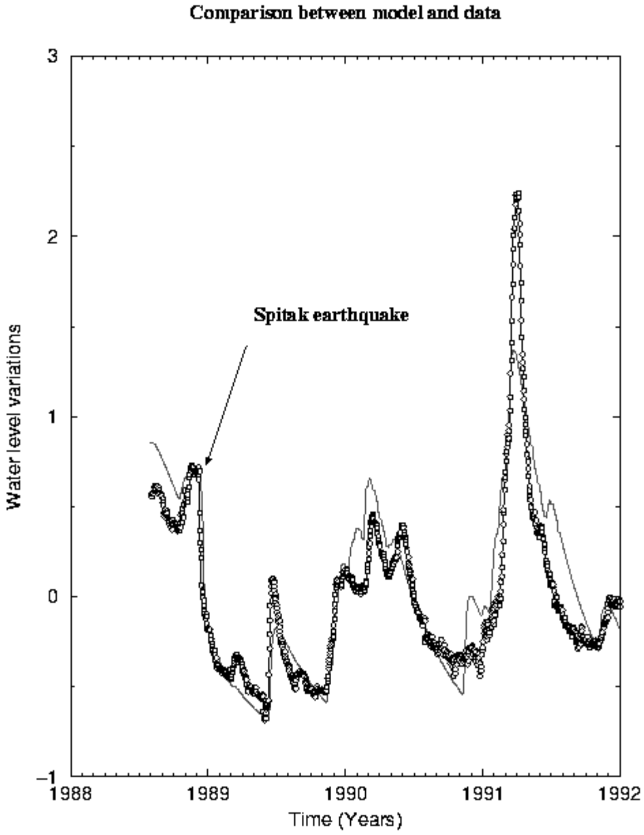
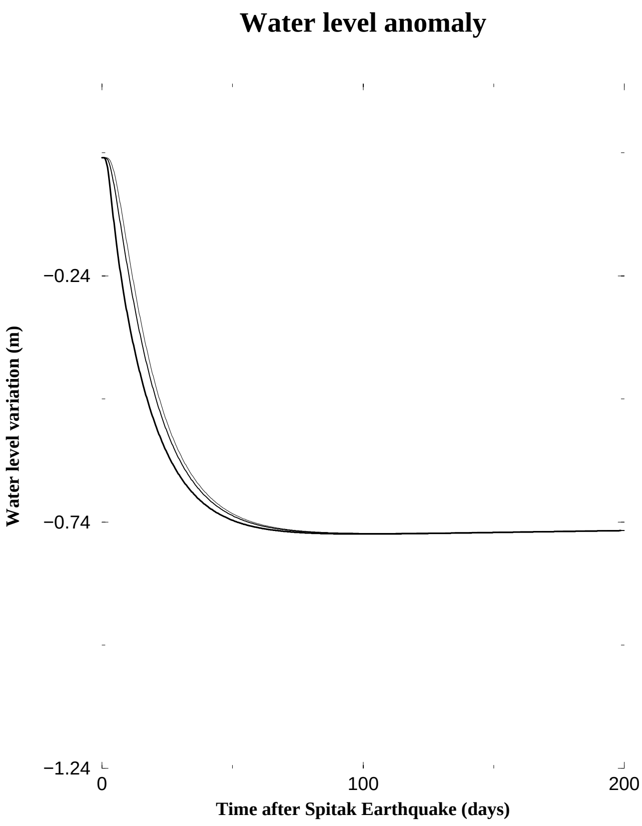


Figure 18.



4 DISCUSSION

$$\Delta V_{\mathrm{f}}/V_{\mathrm{f}}=\rho g \Delta h \times \chi_{\mathrm{f}}\,,$$

$$\Delta V_{\mathrm{f}}/V_{\mathrm{f}}=\Delta V_{\mathrm{frac}}/V_{\mathrm{f}}=(\Delta V_{\mathrm{frac}}/V_{\mathrm{frac}})\times(V_{\mathrm{frac}}/V_{\mathrm{f}})$$

$$(\Delta V_{\mathrm{frac}}/V_{\mathrm{frac}})=(\Delta V_{\mathrm{f}}/V_{\mathrm{f}})/(V_{\mathrm{frac}}/V_{\mathrm{f}})$$

4.1.1 Can seismic waves produce variations of porosity and permeability compatible with the requirements of the model?

4.1.2 Can the damage responsible for the global variation of permeability and that responsible for the zones of increased porosity coincide spatially?

[illegible]

5 CONCLUSIONS

[illegible]

ACKNOWLEDGMENTS

[illegible]

REFERENCES

[illegible] *et al.* [illegible] *Tectonophysics,* **213,** [illegible]

[illegible] *Random Data: Analysis and Measurement Procedures,* [illegible]

[illegible] *Global biogeochem. Cycles,* **7,** [illegible]

[illegible] *J. geophys. Res.,* **72,** [illegible]

[illegible] *J. appl. Phys,* **38,** [illegible]

[illegible] *Pure appl. Geophys,* **116,** [illegible]

[illegible] *Mechanika Podgotowki Tectonisheskowo Semletrjasenia,* [illegible]

[illegible] *Physical and Chemical Hydrogeology,* [illegible]

[illegible] *Dynamics of Fluids in Hierarchical Porous Media,* [illegible]

[illegible] *Water Resources Res.,* **7,** [illegible]

[illegible] *Proc. 24th US Symp. on Rock Mechanics* [illegible]

[illegible] *J. geophys. Res.,* **72,** [illegible]

[illegible] *Waterways Experiment Station Corps of Engineers US Army Bull.,* [illegible]

[illegible] *J. geophys. Res.,* **96,** [illegible]

[illegible] *Tectonophysics,* **211,** [illegible]

[illegible] *J. geophys. Res.,* **98,** [illegible]

[illegible] *Water Resources Res.,* **9,** [illegible]

[illegible] *Pure appl. Geophys.,* [illegible]

[illegible] *J. geophys. Res.,* **103,** [illegible]

[illegible] *Pure appl. Geophys.,* **149,** [illegible]

[illegible] *J. geophys. Res.,* **94,** [illegible]

[illegible] *J. geophys. Res.,* **93,** [illegible]

[illegible] *Nature,* **373,** [illegible]

[illegible] *Geophys. J. Int.,* [illegible]

[illegible] *Geograph. Rev.,* **38,** [illegible]

[illegible] *Publ. Climatol.,* **30,** [illegible]

APPENDIX A: MODELLING COUPLED FLUID FLOW AND FRACTURING

[illegible]

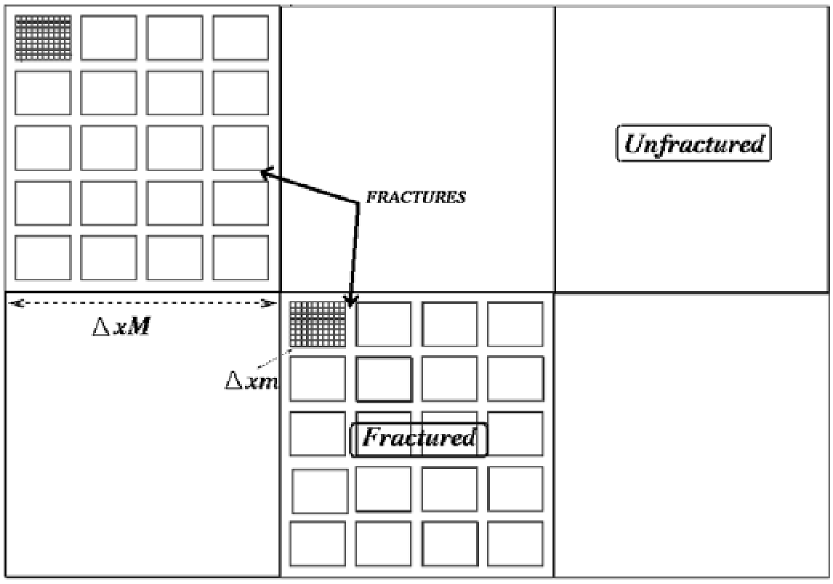


Figure A1. [illegible] Δx [illegible] Δx [illegible]

[illegible]

$$S_{\mathrm{f}} \frac{\partial(P_{\mathrm{f}})}{\partial t} = \nabla(K_{\mathrm{f}}(\eta)\nabla P_{\mathrm{f}}) + Q_{\mathrm{ext}} + Q_{\mathrm{m}}\,, \qquad [illegible]$$

[illegible] P [illegible] S [illegible] K [illegible] η [illegible] Q [illegible] Q [illegible]:

$$Q_{\mathrm{m}} = -\sum_i \frac{1}{\Omega_i}\int_{\Omega_i} \frac{\partial(\Phi_{\mathrm{m}}\rho_{\mathrm{m}})(\xi, t)}{\partial t}\, d\xi\,, \qquad [illegible]$$

[illegible] i [illegible] Ω_i [illegible] Φ [illegible] ρ [illegible]

$$S_{\mathrm{m}} \frac{\partial(P_{\mathrm{m}})}{\partial t} = \nabla(K_{\mathrm{m}}(\eta)\nabla P_{\mathrm{m}})\,, \qquad [illegible]$$

[illegible] P [illegible] S [illegible] K [illegible] Δx [illegible] Δx [illegible] T [illegible] T [illegible] $T \ll T$ [illegible] T [illegible]