



Imaging the Flow Networks from a Harmonic Pumping in a Karstic Field with an Inversion Algorithm

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Imaging in a Model the Flow Networks Generated by Harmonic Pumping Tests in a Karstic Field (Lez Aquifer, France)

AGU FALL MEETING

New Orleans 11-15 Dec. 2017

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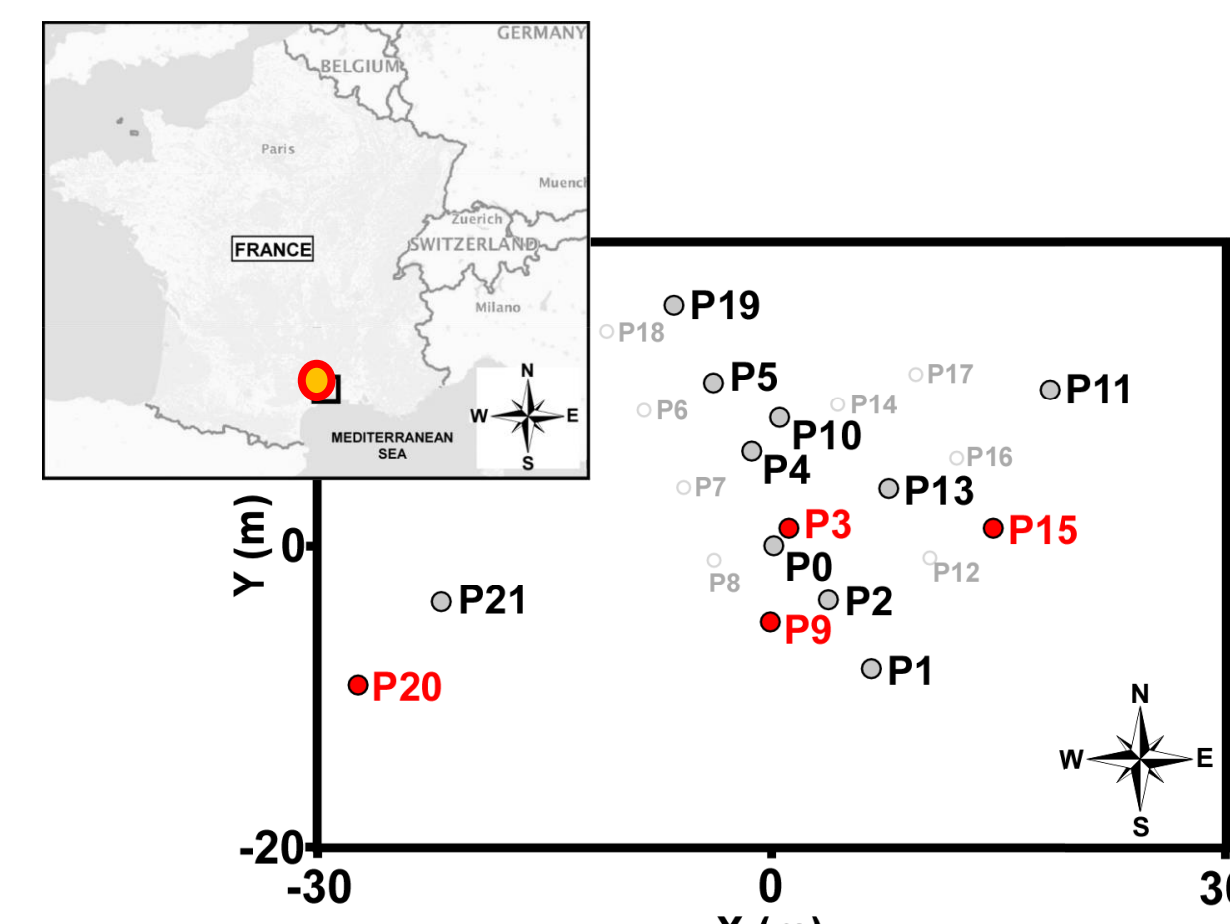
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For the protection and the management of the water resources, it is necessary to understand and localize the flow paths in the ground. In this work [1], we present a method to interpret the flow paths generated from a pumping investigation in a karstified aquifer. This method uses several recent and innovative tools, such as harmonic pumping tests (pumping with a sinusoidal signal, which appear to be more efficient for highlighting the heterogeneities), and imageries of the flows highlighted by the pumping tests in a distributed model, produced with a Cellular Automata-based Deterministic Inversion (CADI).

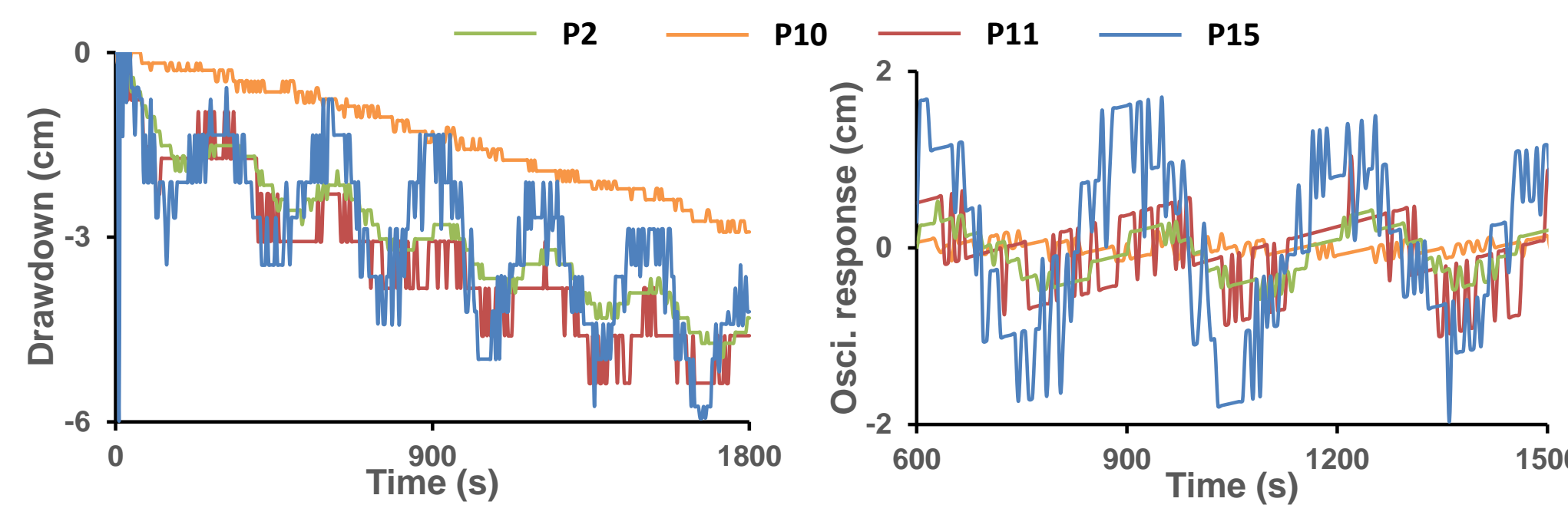
HARMONIC INVESTIGATION AND MEASUREMENT PROCESSING

We have led a harmonic pumping investigation in the Terrieu experimental site in France (fig.1) with 4 successive pumping points. This investigation consists in generating an oscillatory pumping signal (characterized by its amplitude and its period) while measuring the drawdown responses in 13 measurement points. For each pumping points we performed the tests with two signal periods: 2min and 5min.



▲ (fig.1) Localization of Terrieu field in France and map of the boreholes distribution (red: pumping points ; red & grey: measurement points ; white: non-used points).

▼ (fig.2) Left: drawdown curves measured in 4 points for a pumping in P15 (5min). Right: oscillatory responses extracted from the drawdown curves by subtracting the linear part.

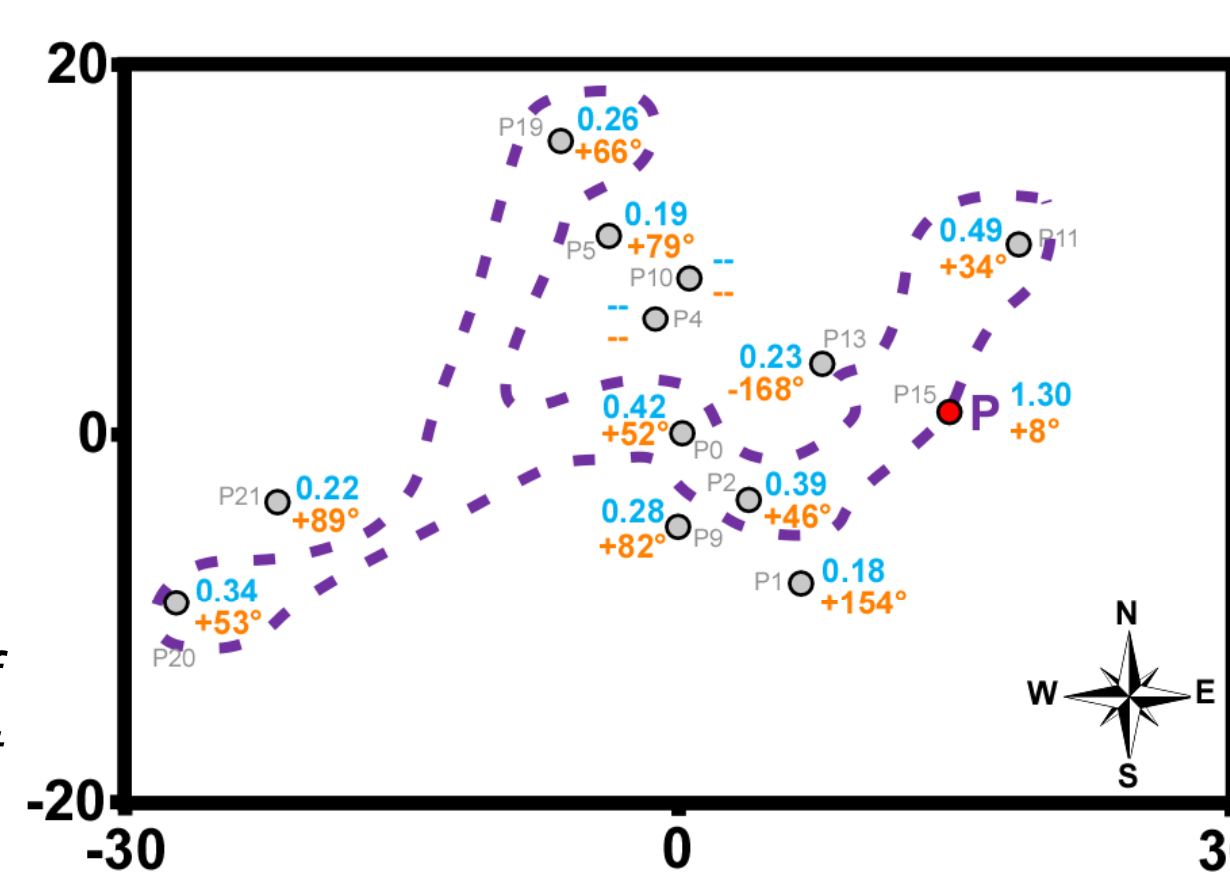


We can extract the oscillatory part of the measured responses by subtracting the linear part from the drawdown curves (fig.2) as shown in [2].

We can estimate the amplitude and phase offset values in the measured responses by performing a FFT on their oscillatory parts. These values permit to characterize different type of responses described in [2]: they highlight either a conduit network connectivity, an hybrid conduit/matrix connectivity, or a matrix connectivity. Therefore, harmonic pumping data are relevant for a karstic network hydraulic tomography.

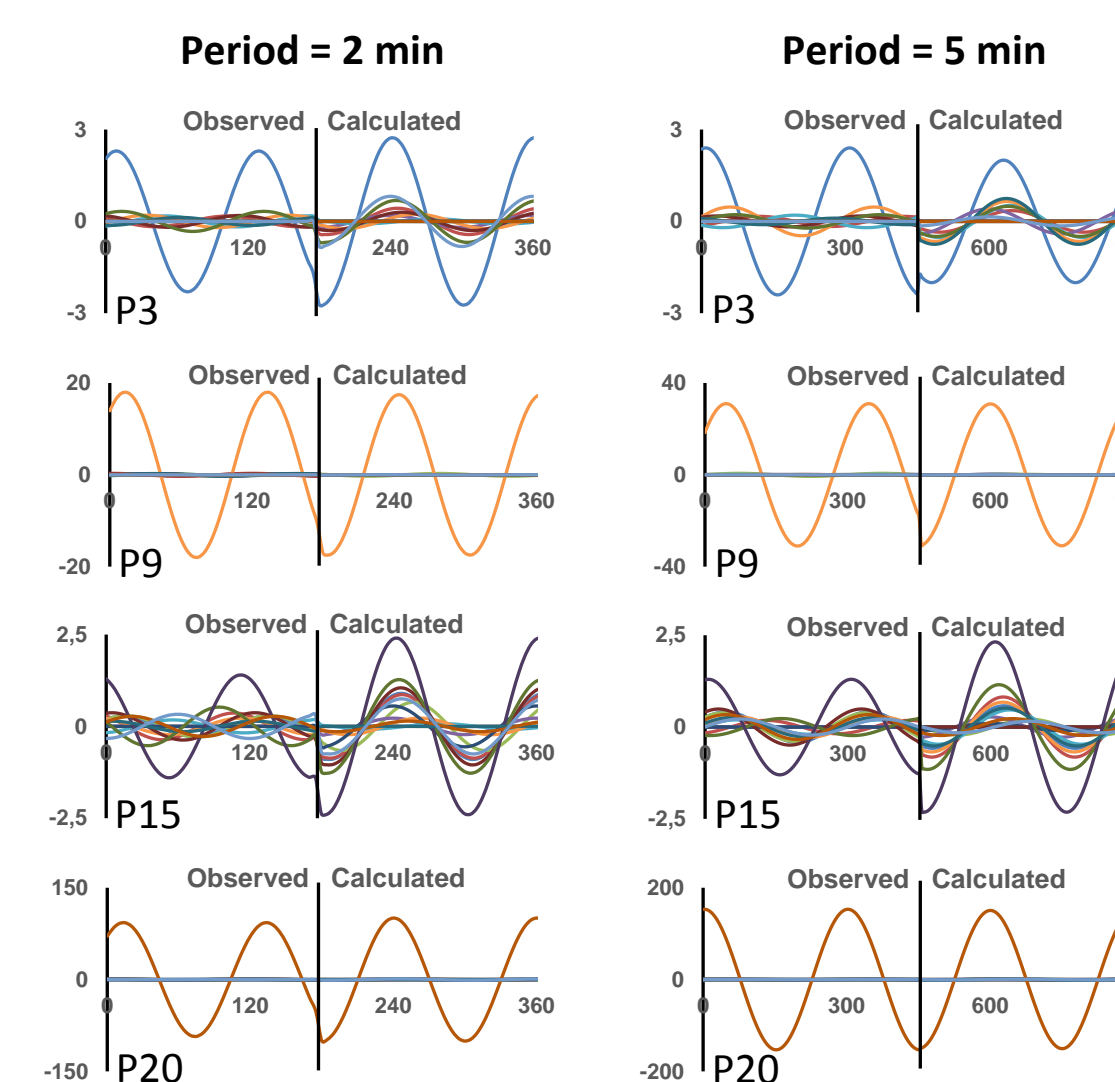
Reporting these values on a map permits a first estimation of the relative positioning of the network by interpreting the connectivity responses (fig.3).

► (fig.3) Map of amplitudes (in blue) and phase offsets (in orange) of the oscillatory responses for a pumping in P15 (5min). Dotted violet lines show a possible connectivity interpreted from this map.



INVERSE MODELING RESULTS

We have applied a Cellular Automata-based Deterministic Inversion (CADI) with a 2D distributed model solved in the frequency domain, in order to find a property distribution able to reproduce the oscillatory responses measured for all pumping tests of the investigation. The CADI method, developed in [3], permits to structure the property distribution in a conduits network, whose geometry is also optimized in accordance with the measured responses. The transmissivity models found by inversion for pumping signals periods of 2min and 5min are presented in (fig.4).



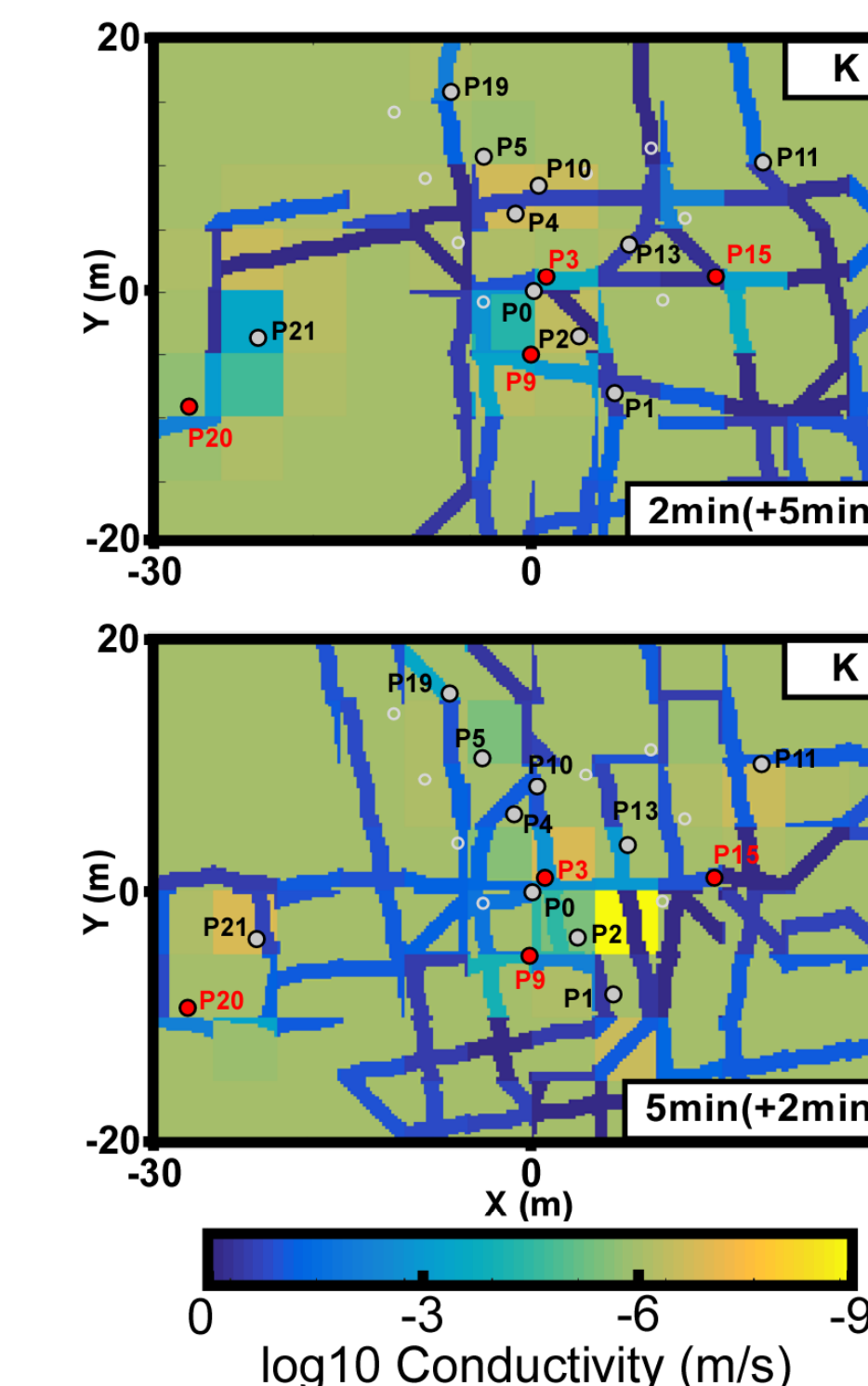
▲ (fig.4) Conductivity models reproducing the responses to pumping periods of 2min (top) and 5min (bottom).

The comparison between the measured signals and the simulated signals are presented in (fig.5). The reproduction of the responses are accurate, except maybe for the P15 simulated signals which are slightly over-estimated, but still correct in proportion.

The maps in (fig.4) permit an interpretation of the connectivity and of the conduit positioning between the measurement boreholes.

The possible conduits network simulate the constrained flows mobilized by the pumping tests for the two different signal periods (2min and 5min). From the results in (fig.4) it appears that the choice of the signal period affects the flow paths generated in the aquifer.

EFFECT OF THE SIGNAL PERIOD



▲ (fig.5) Flow connectivity interpreted from the estimation (fig.3), the separate inversion (fig.4) and the joint inversion (fig.6). Inversion started from the 2min result (top) and the 5min result (bottom).

	PERIOD = 2 MIN			PERIOD = 5 MIN		
	Est.	Sep.	Joint	Joint	Sep.	Est.
P0	○	⊗	⊗	×	×	×
P1	×	×	×	×	×	×
P2	×	×	×	×	×	×
P3	×	×	×	×	×	×
P4	×	×	×	×	×	×
P5	×	×	×	×	×	×
P9	×	×	×	×	×	×
P10	×	×	×	×	×	×
P11	×	×	×	×	×	×
P13	×	×	×	×	×	×
P15	×	×	×	×	×	×
P19	×	×	×	×	×	×
P20	×	×	×	×	×	×
P21	×	×	×	×	×	×

▲ (fig.7) Flow connectivity interpreted from the estimation (fig.3), the separate inversion (fig.4) and the joint inversion (fig.6).

× : in a conduit =
conduit connectivity response,
⊗ : very close to a conduit (< 0.5 m) =
conduit connectivity response,
○ : close to a conduit (< 2 m) =
hybrid connectivity response,
- : in the matrix =
matrix connectivity response

The models found from joint inversions (both periods) in (fig.6) do not permit an as good reproduction of the responses amplitudes as in (fig.5): the reproduction of the 5min responses requires a dense flow network and the 2min responses a dispersed one.

The interpreted connectivity from each model (fig.7) show that 93% of the boreholes have a similar connectivity in the joint results and only 53% in the separate results. This connectivity information is already mostly present in the 2min result (93%).

Globally, our results indicate that a lower pumping period tends to characterize the well connectivity through the principal flow paths (conduits network), while a higher pumping period tends to rather characterize local flows around the borehole (conduit + fractures).

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