The Impact of 921 Chi-Chi Earthquake on Groundwater of the Choshuichi Alluvial Fan, Taiwan: Isotope and hydrological evidences

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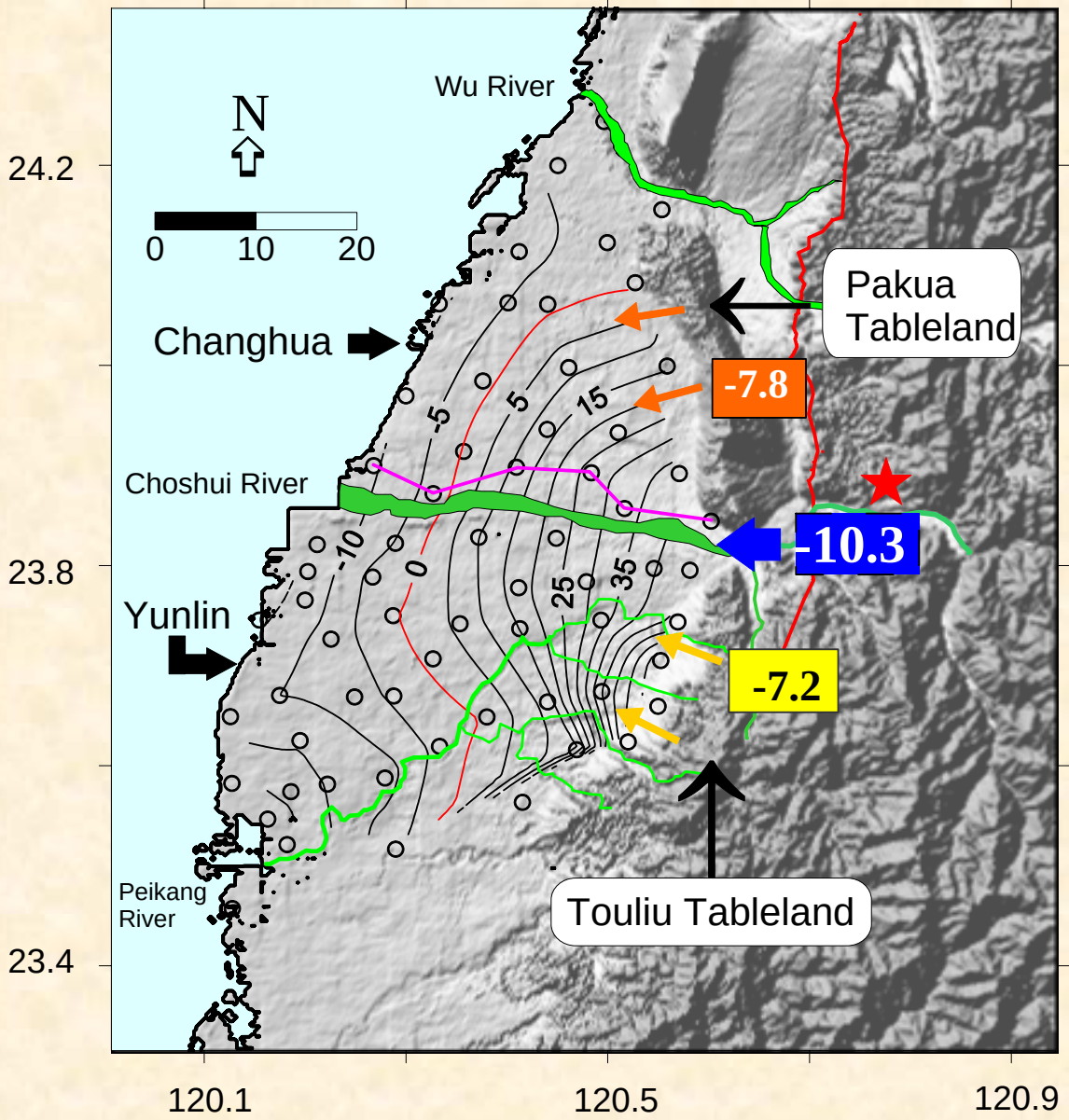
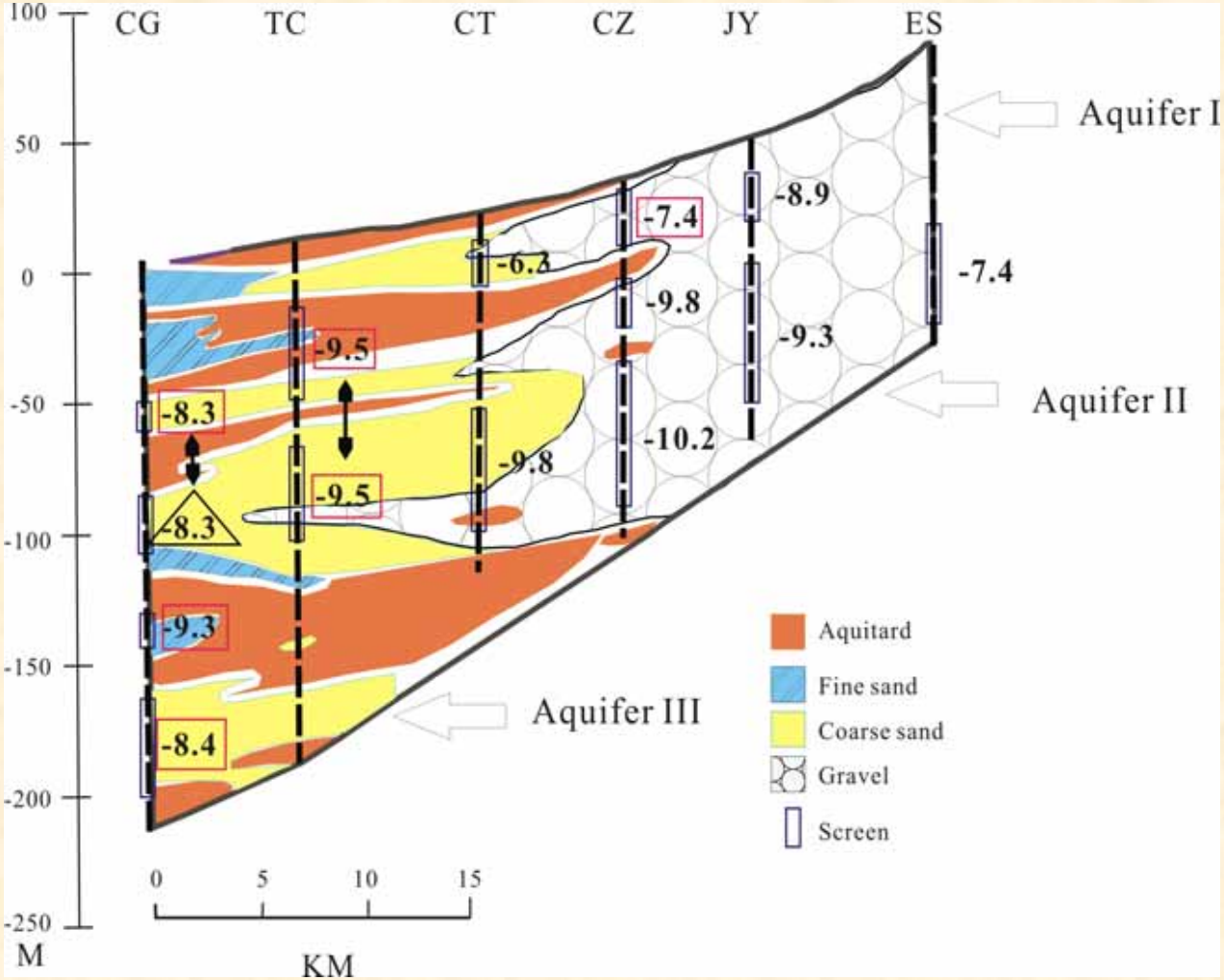
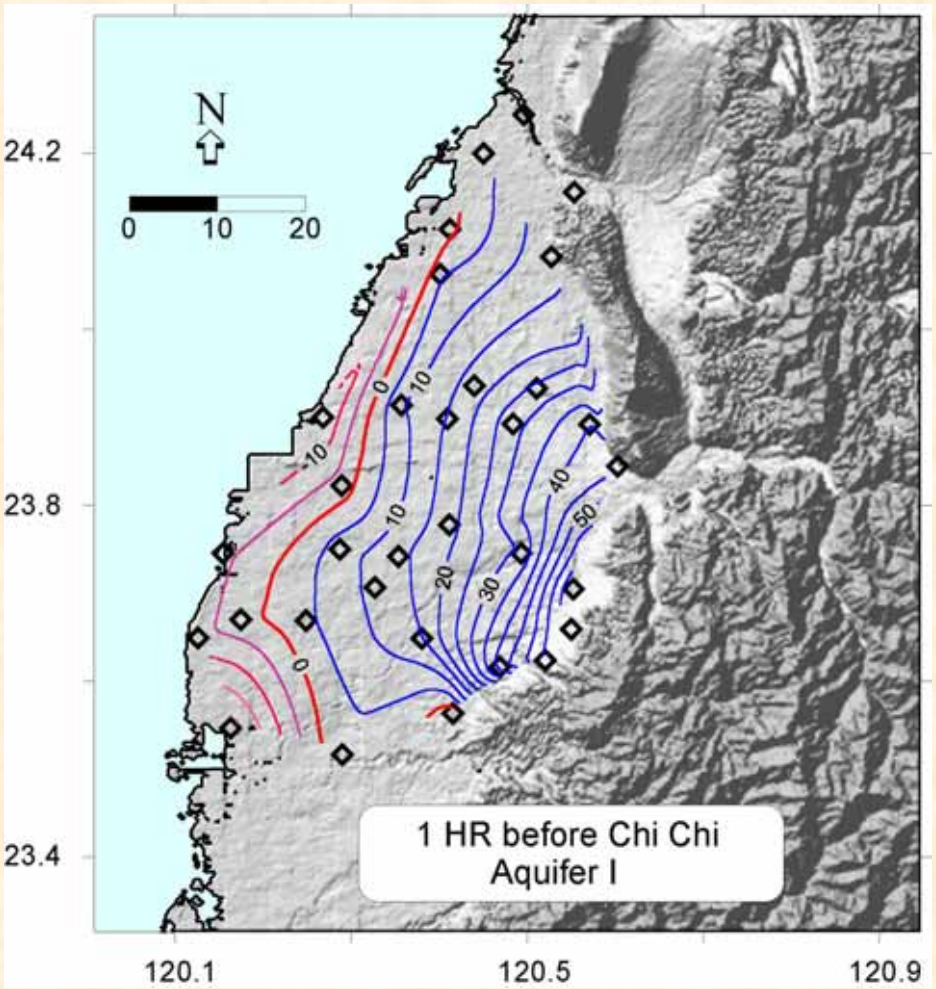
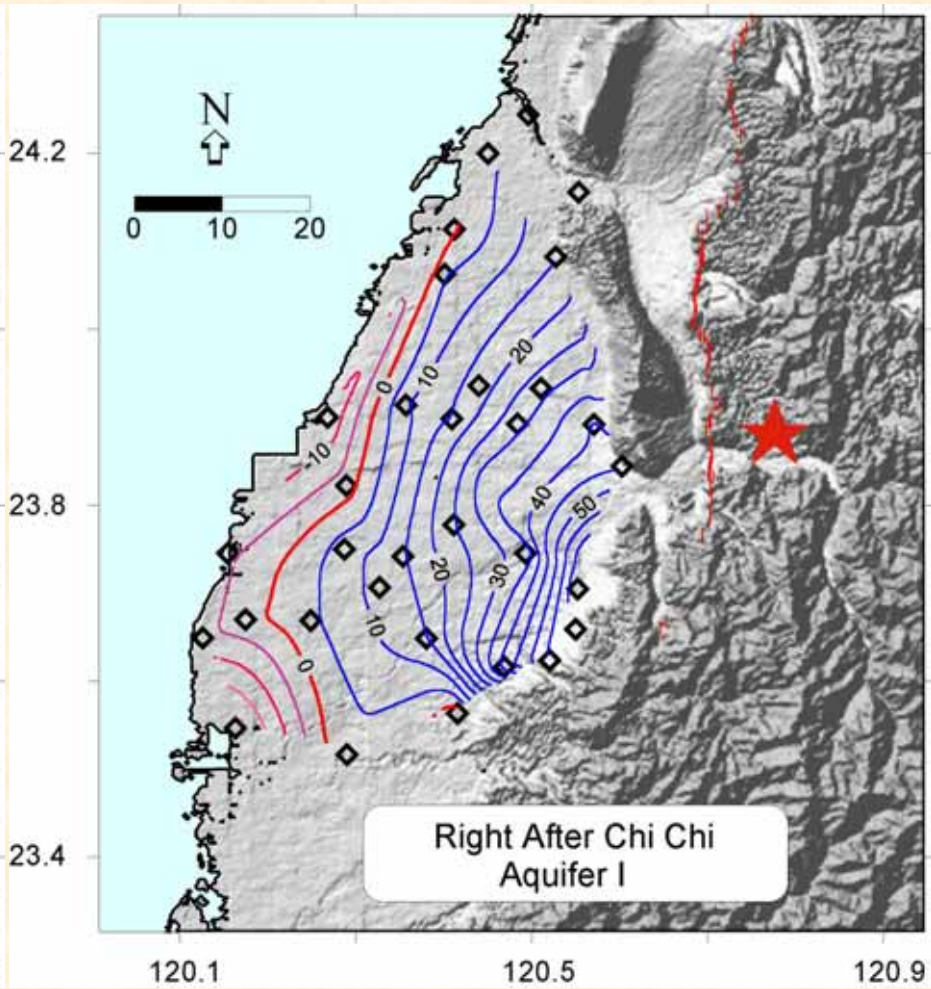
Choshui River alluvial fan and 1999 Chi-Chi Earthquake (red star). The Choshui River (green color) flows through the middle of the fan and separates two sections: northern Changhua and southern Yunlin. Groundwater stations of the monitoring network are shown in open circles. Groundwater levels on September 20 1999 (one hour before the earthquake) of Aquifer II are shown as contour lines with 5 meter interval. The zero meter level is expressed as thin red line. Negative groundwater levels are found on the west side of the zero meter line. Oxygen isotope compositions of modern recharges from three sources (top: Pakua Tableland (-7.8‰); middle: Choshui River (-10.3‰); lower: Touliu Tableland (-7.2‰)) are illustrated.



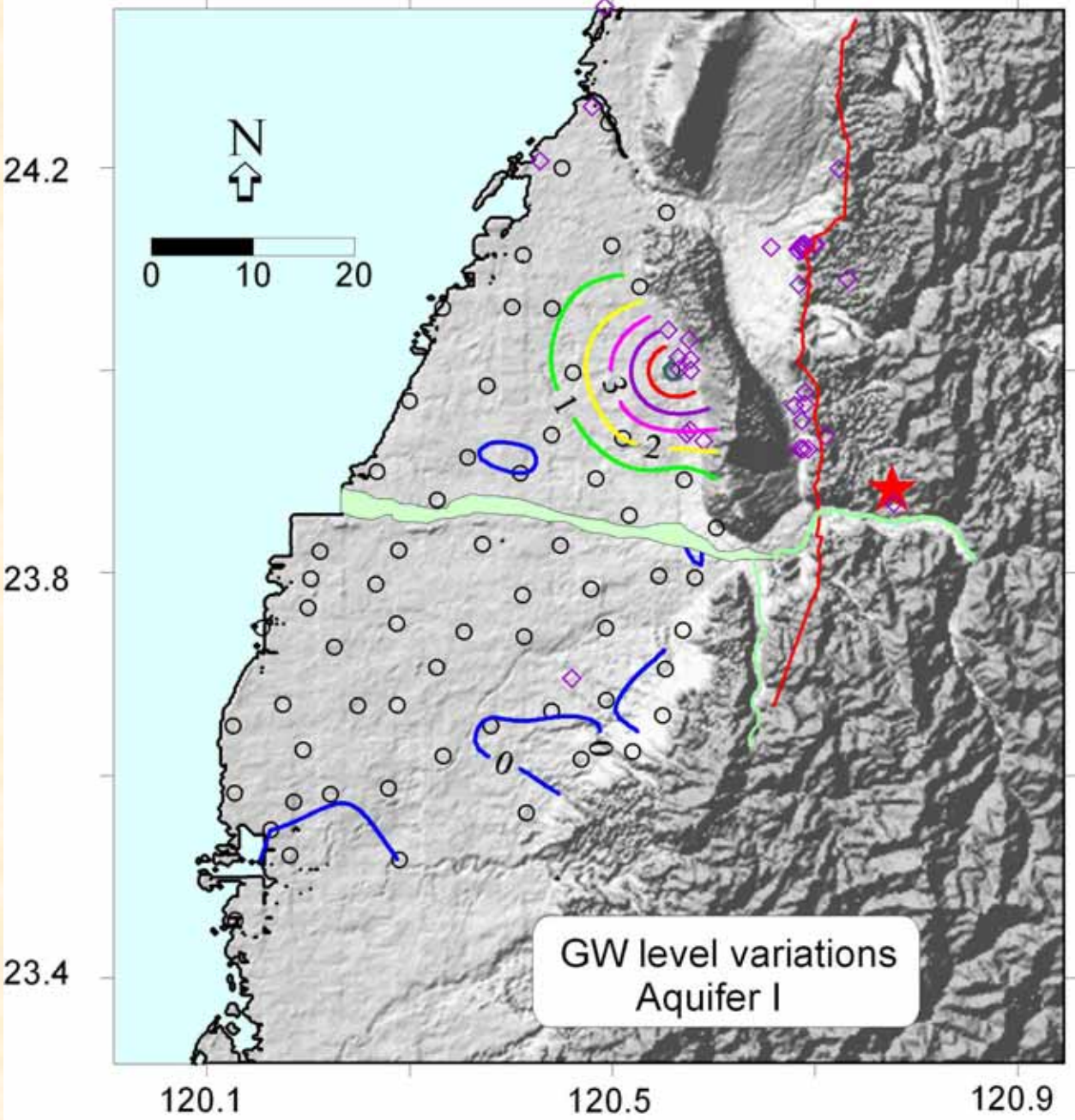
Cross-section from Ershui (ES) to Shikong (CG) shows the general feature of three aquifers in the Choshui River alluvial fan. Three aquifers can be identified from top (Aquifer I) to bottom (Aquifer III). The vertical dashed lines represent boreholes. Numbers are the oxygen isotope values after the Chi-Chi earthquake for each sampling sites. Squared figures are those that shifted towards more depleted values, triangle figure is the one that became more enriched, after the earthquake.

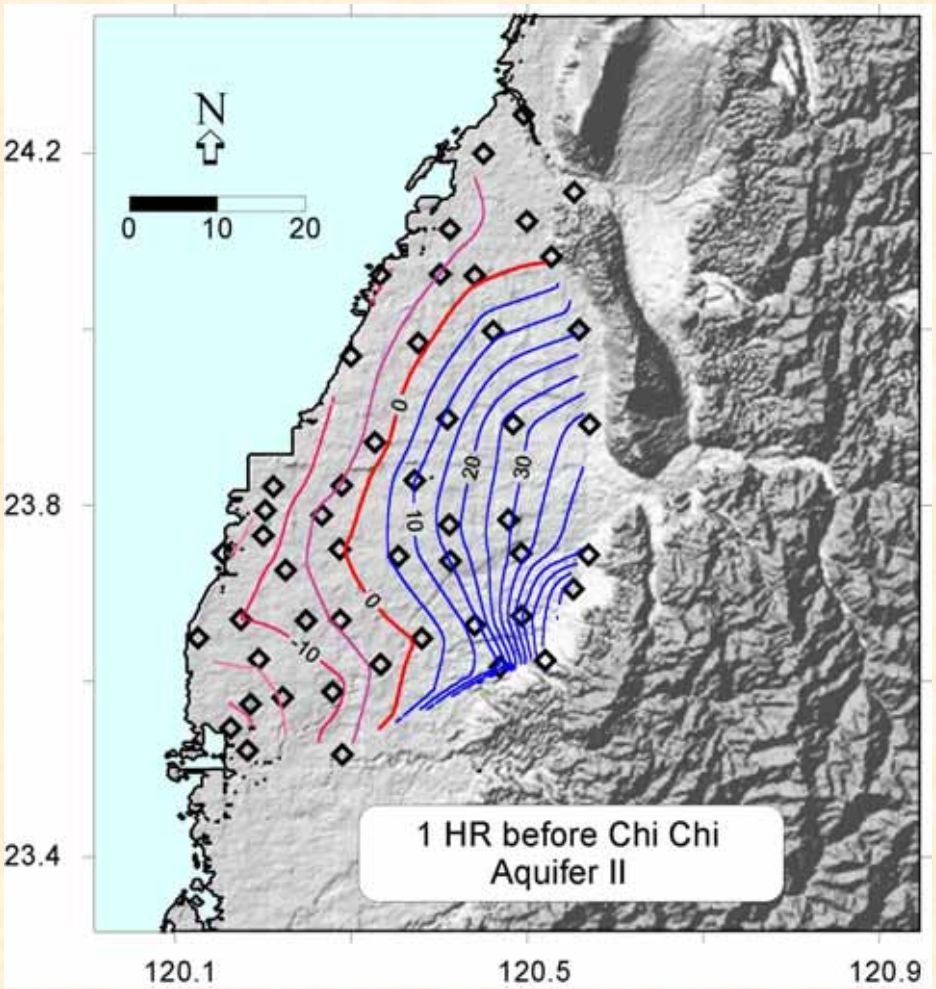


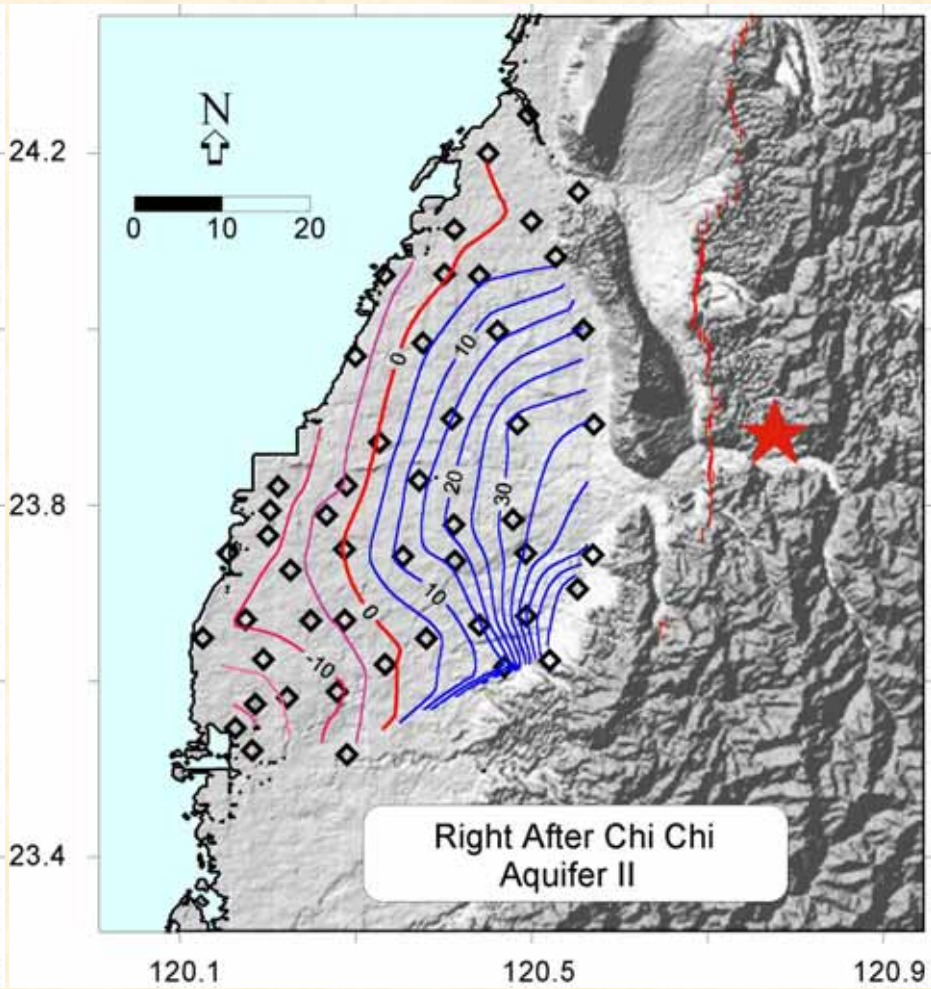

N
0 10 20
24.2
23.8
23.4
120.1
120.5
120.9
-10
0
10
20
30
40
50
1 HR before Chi Chi
Aquifer I


N
0 10 20
24.2
23.8
23.4
120.1
120.5
120.9
-10
0
10
20
30
40
50
Right After Chi Chi
Aquifer I

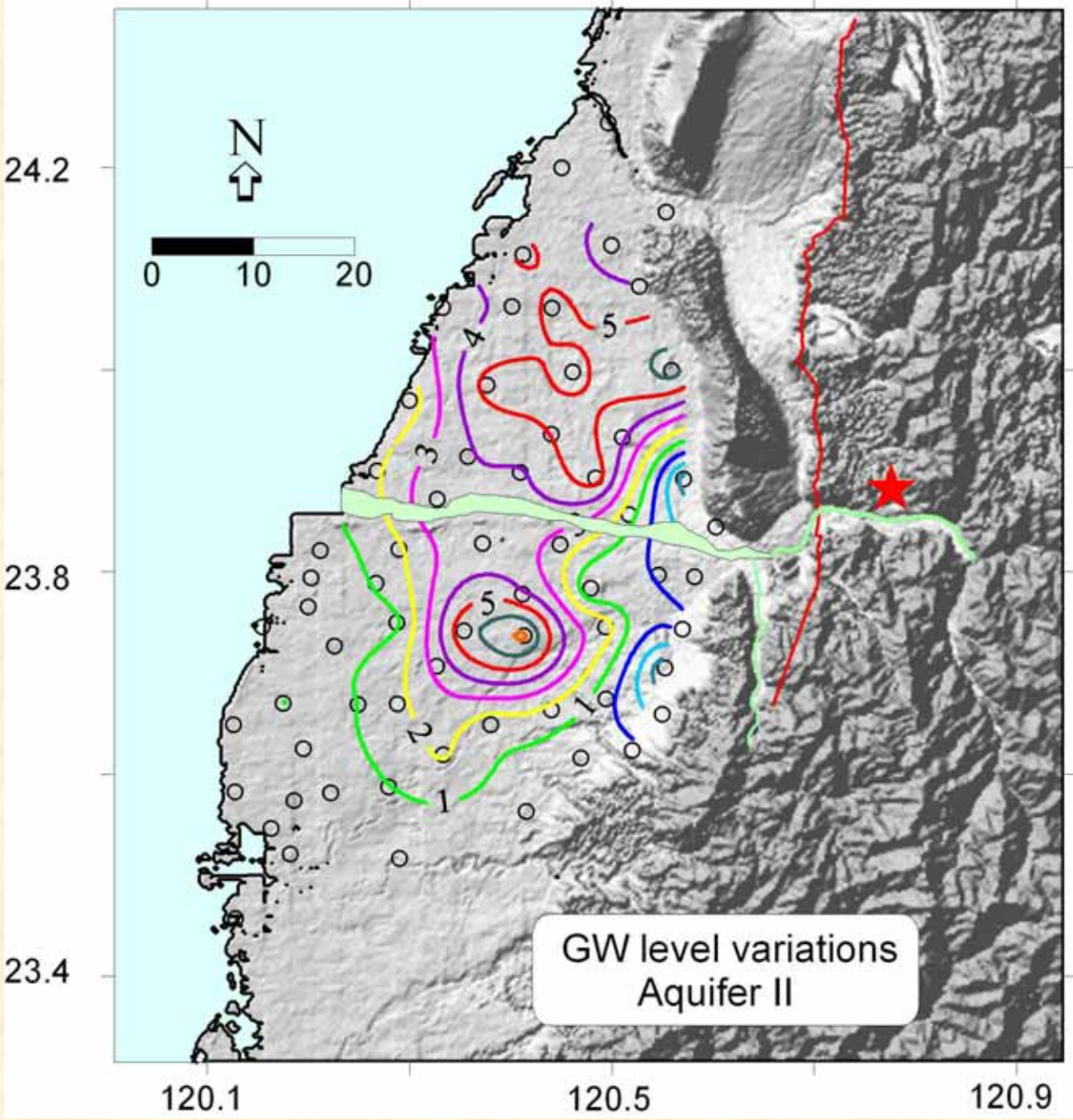
Coseismic groundwater-level contours for aquifers of Choshui River Alluvial Fan colored 1-m interval, during the Chi-Chi Earthquake. Red contour lines represent the coseismic groundwater level change higher than 5 meters during the earthquake.

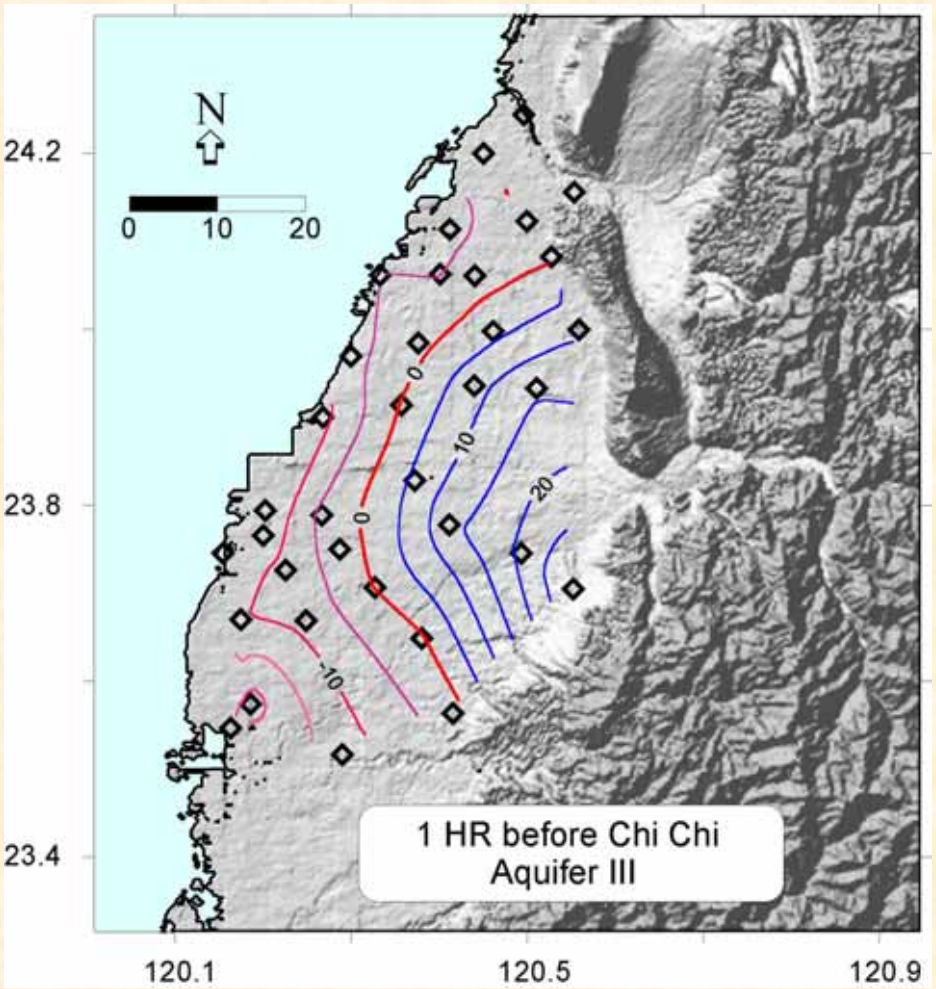


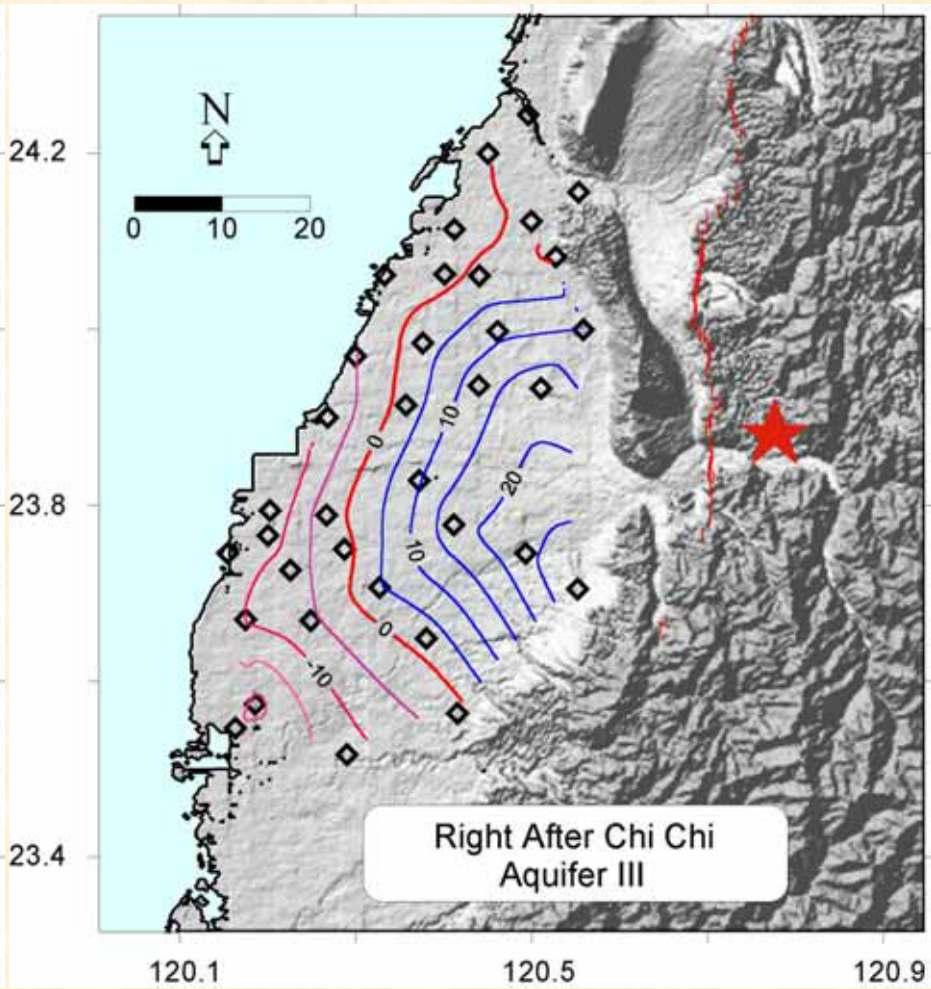

N
0 10 20
24.2
23.8
23.4
0
10
20
30
-10
1 HR before Chi Chi
Aquifer II
120.1
120.5
120.9


N
0 10 20
24.2
23.8
23.4
0
10
20
30
-10
Right After Chi Chi
Aquifer II
120.1
120.5
120.9

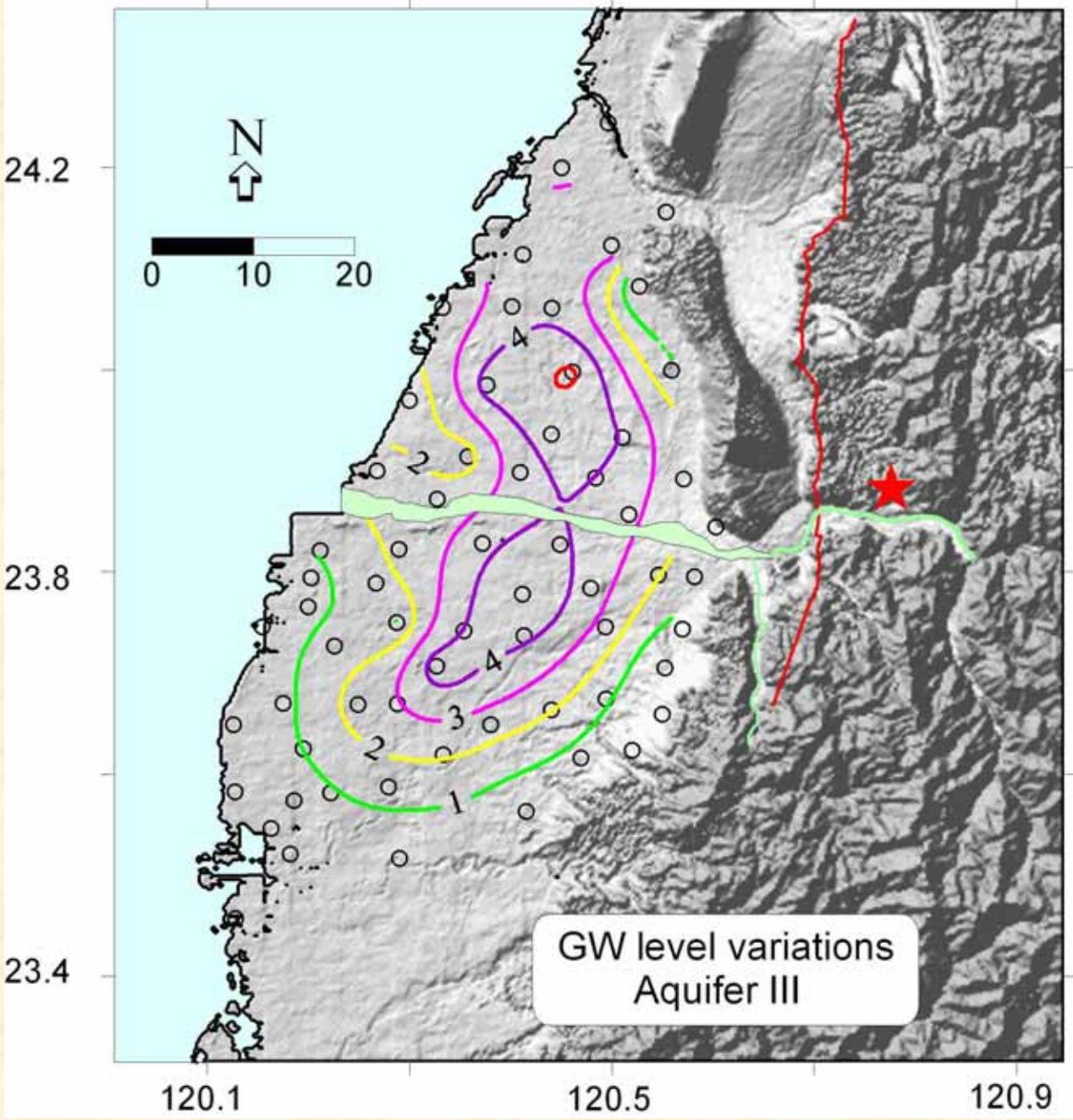
Coseismic groundwater-level contours for aquifers of Choshui River Alluvial Fan colored 1-m interval, during the Chi-Chi Earthquake. Red contour lines represent the coseismic groundwater level change higher than 5 meters during the earthquake.

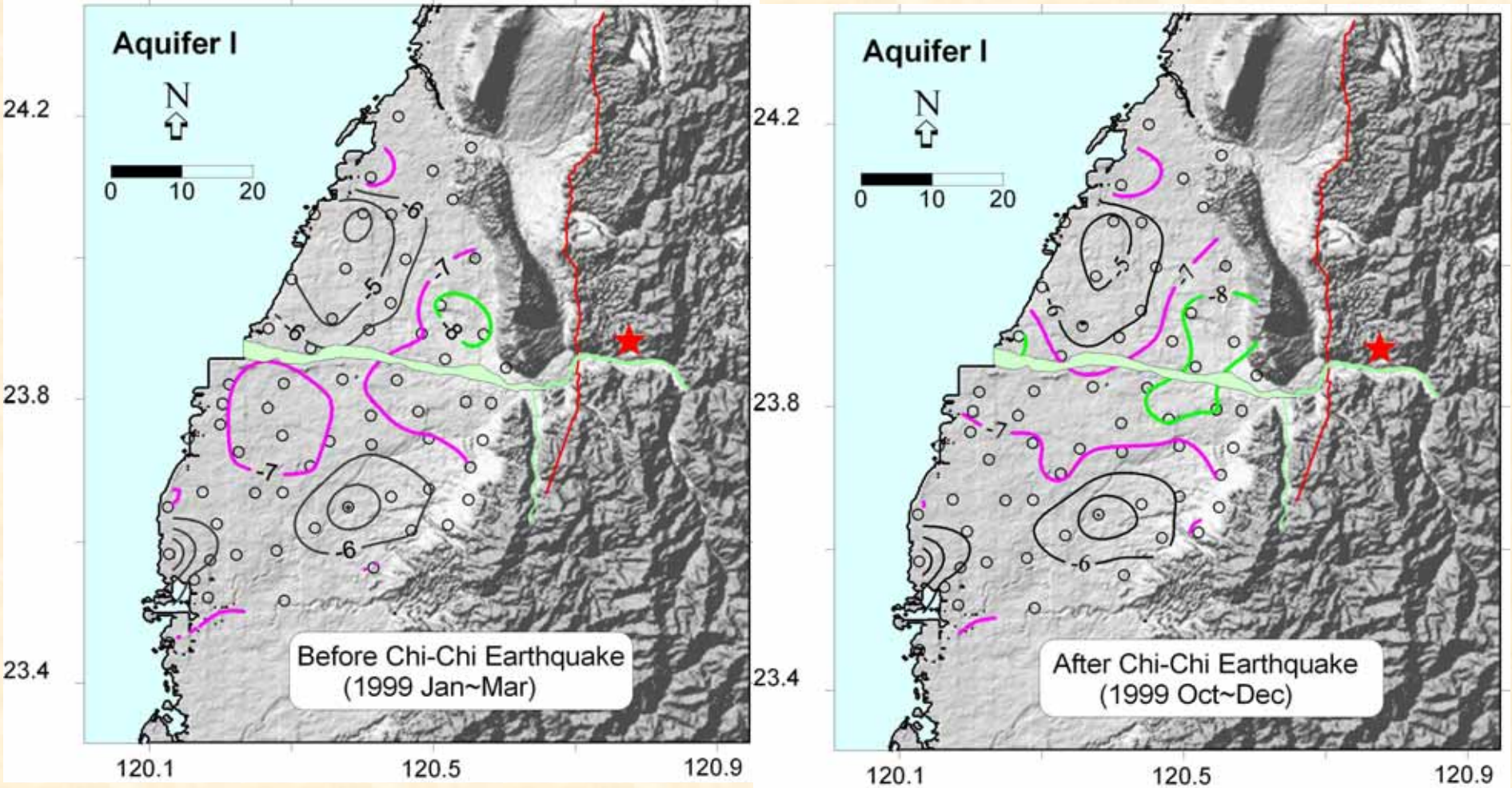



N
0 10 20
24.2
23.8
23.4
120.1
120.5
120.9
0
0
10
20
-10
1 HR before Chi Chi
Aquifer III

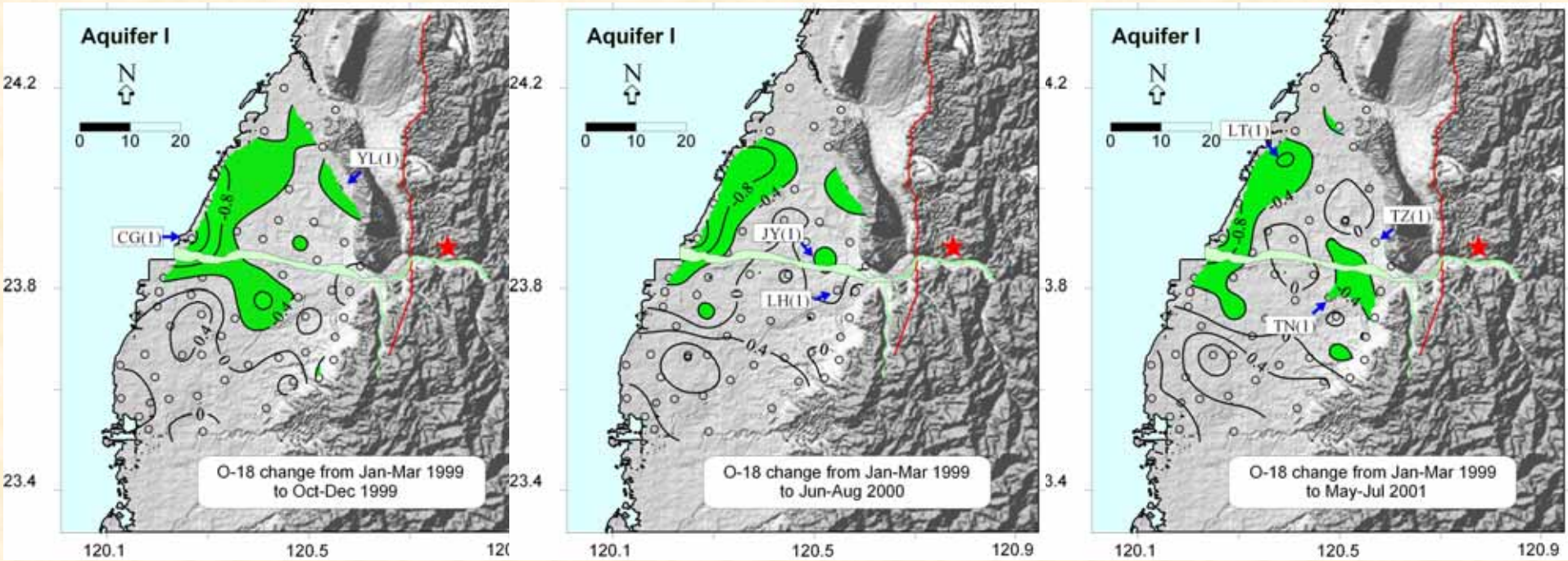

N
0 10 20
24.2
23.8
23.4
120.1
120.5
120.9
0
10
20
10
0
-10
Right After Chi Chi
Aquifer III

Coseismic groundwater-level contours for aquifers of Choshui River Alluvial Fan colored 1-m interval, during the Chi-Chi Earthquake. Red contour lines represent the coseismic groundwater level change higher than 5 meters during the earthquake.

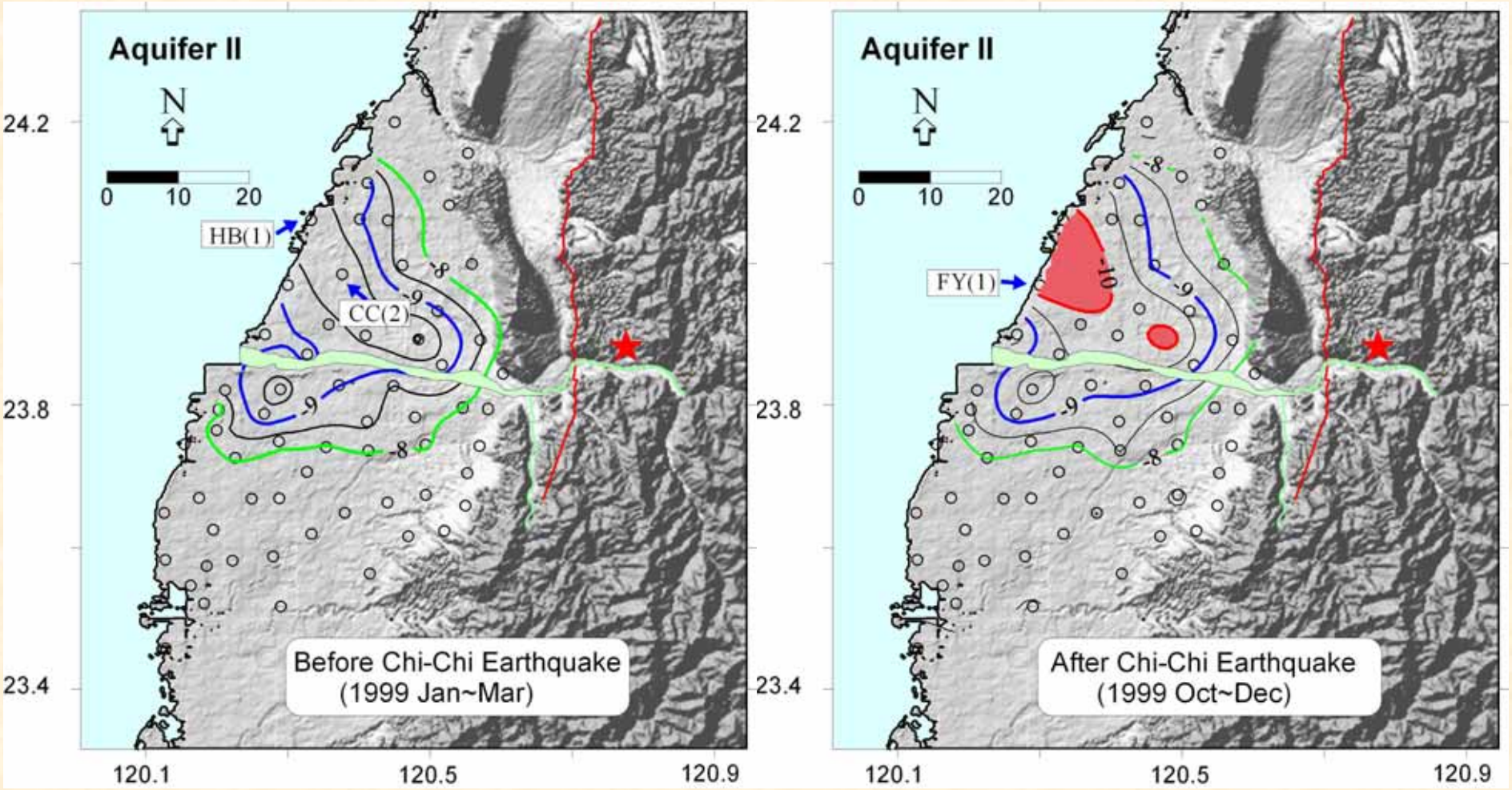




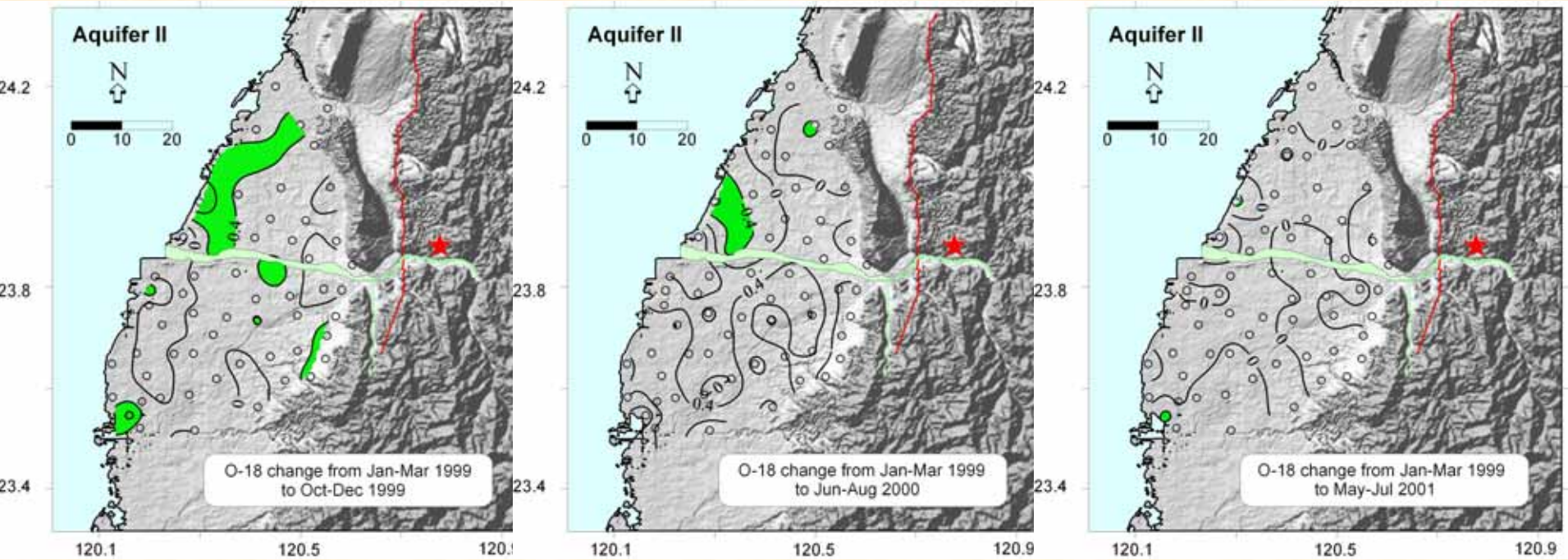
Oxygen isotope contours for Aquifer I of 1999. Open circles are the sampling wells. Figures illustrate the absolute $\delta^{18}O$ values in 1‰ interval: (a) Jan-Mar 1999; (b) Oct-Dec 1999. Pink lines are -7‰ contours and green lines represent the -8‰ contours.



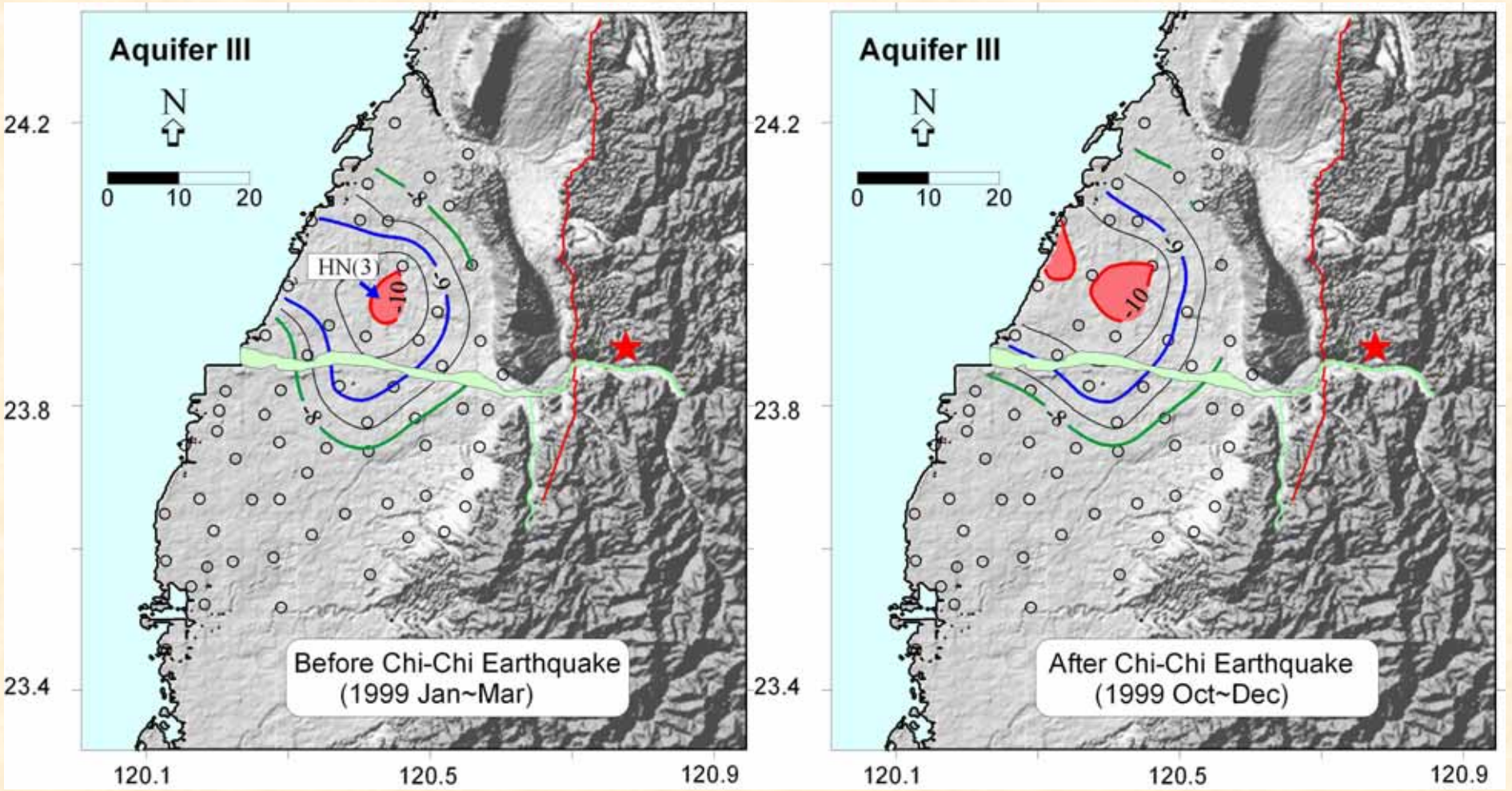
Figures show the $\delta^{18}O$ difference in 0.4‰ interval of Jan-Mar 1999 to: (a) Oct-Dec 1999 values; (b) Jun-Aug 2000 values; (c) May-Jul 2001 values. Green-colored areas stand for depleted $\delta^{18}O$ changes more than -0.4‰.



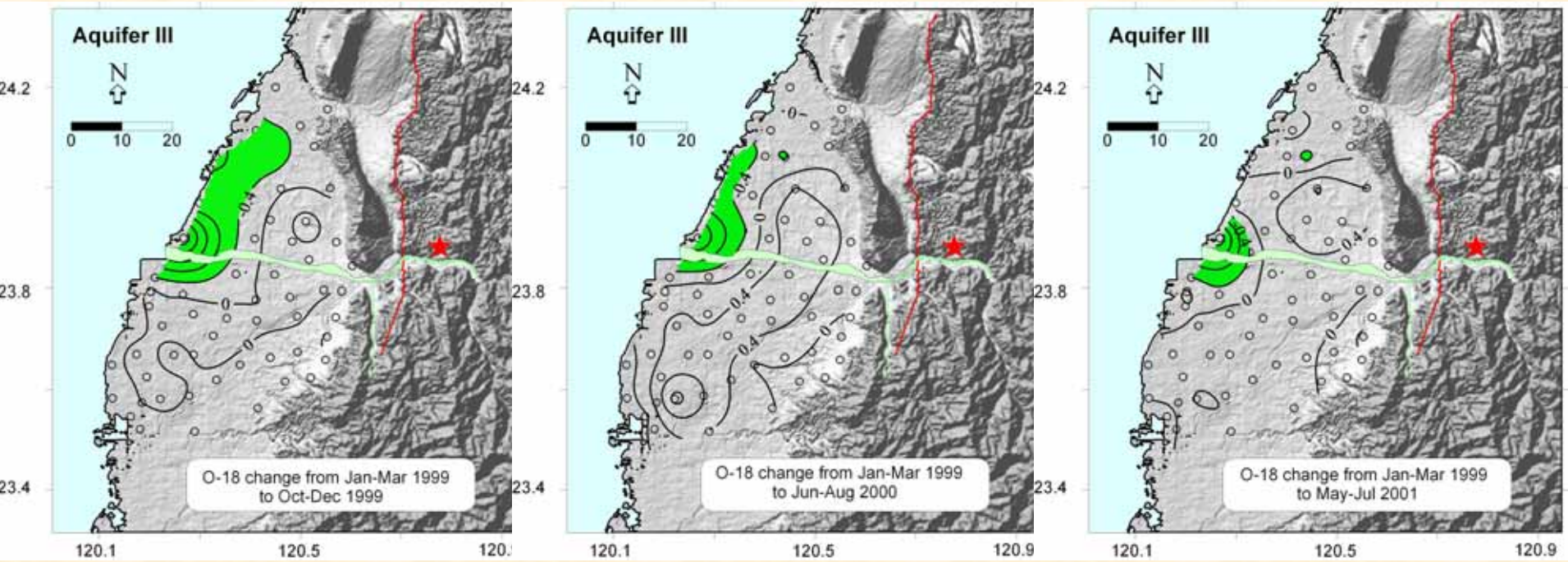
Oxygen isotope contours for Aquifer II from 1999. Open circles are the sampling wells. Figures illustrate the absolute $\delta^{18}O$ values in 0.5‰ interval: (a) Jan-Mar 1999; (b) Oct-Dec 1999. Blue lines are -9‰ contours and green lines represent the -8‰ contours. Red-colored area illustrate the $\delta^{18}O$ values depleted than -10‰.



Figures show the $\delta^{18}O$ difference in 0.4‰ interval of Jan-Mar 1999 to: (a) Oct-Dec 1999 values; (b) Jun-Aug 2000 values; (c) May-Jul 2001 values. Green-colored areas stand for depleted $\delta^{18}O$ changes more than -0.4‰.



Oxygen isotope contours for Aquifer III. Open circles are the sampling wells. Figures (a) and (b) illustrate the absolute $\delta^{18}O$ values in 0.5‰ interval: (a) Jan-Mar, 1999; (b) Oct-Dec 1999. Blue lines are -9‰ contours and green lines represent the -8‰ contours. Red-colored area illustrate the $\delta^{18}O$ values depleted than -10‰.



Figures show the $\delta^{18}O$ difference in 0.4‰ interval of Jan-Mar 1999 to: (a) Oct-Dec 1999 values; (b) Jun-Aug 2000 values; (c) May-Jul 2001 values. Green-colored areas stand for depleted $\delta^{18}O$ changes more than -0.4‰.

Conclusions

- Oxygen isotope compositions measured before and after the Chi-Chi earthquake for monitoring wells in the Choshui River fan reveal distinct and interesting patterns for various aquifers. For the top Aquifer I, it is relatively enriched in $\delta^{18}O$ values, indicating sources with enriched oxygen isotope compositions were mixed into it. After the Chi-Chi earthquake, monitoring wells in the proximal area slightly shifted toward relatively depleted values till summer 2001, suggesting that the origin from the Choshui River increased and remained as such for more than one year.
- The isotope changes after the earthquake were even more evident for confined aquifers II and III with much depleted $\delta^{18}O$ values that mainly derived from the Choshui River, especially in the Changhua section where the old river channels positioned, suggesting enhanced exchanges of water between the Choshui River and the groundwater.

Conclusions (cont.)

- Unexpected low $\delta^{18}O$-contour patterns were found in the remote northwestern coastal region, not in the proximal area close to the Choshui River origin. Vertical mixing among aquifers with source under the Aquifer III is interpreted as the likely cause, but a $\delta^{18}O$-depleted water source off the current shoreline might also play a possible role. The convergence of both $\delta^{18}O$ values and coseismic groundwater level changes (*Cw*) after the earthquake for some wells provides additional evidence for water exchanges between aquifers, which implies enhanced permeability due perhaps to the fracturing and breaching of aquitards. The effect of earthquake on the groundwater flow persisted at least one year in Aquifer II, and even longer in Aquifer III.

Conclusions (cont.)

- The contours of coseismic groundwater-level exhibit quite different patterns for unconfined and confined aquifers, though they all had great positive variations in the Choshui River fan. Most liquefaction on the Choshui River fan occurred in an area of ~100 km2 west of the Pakua Tableland in Aquifer I, where coseismic groundwater level changes (*Cw*) exceeded 3m. There is no correlation of *Cw* contours of aquifers II and III with the occurrence of liquefaction, suggesting the liquefaction happened only in the upper aquifer. Little similarity was found between the spatial patterns of *Cw* and oxygen isotope change. Obviously, the processes that caused the coseismic water-level change did not induce any significant geochemical changes, and the processes that caused the geochemical changes did not produce any significant coseismic water-level change.