Present-day stress field vs faults: some examples in Italy

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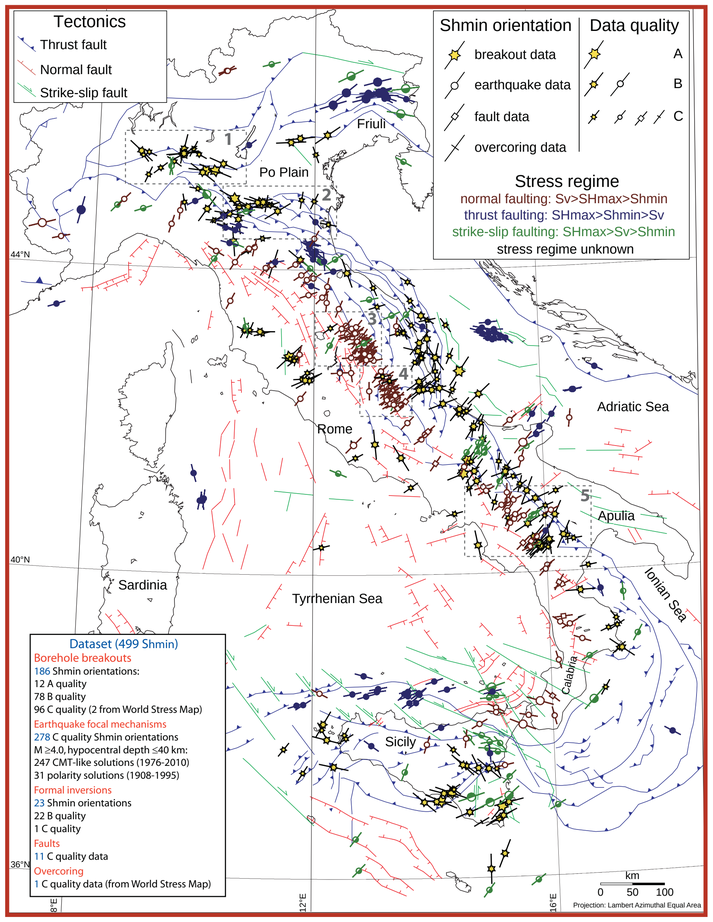
The italian present-day stress map



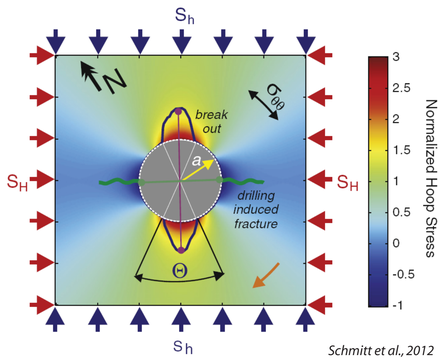
Montone et al., 2012

INTRODUCTION

The italian present-day crustal stress map includes 499 data of A–C quality relative to borehole breakouts, earthquake focal mechanisms and active faults. The alignment of horizontal stresses, closely matches the ~N–S first order stress field orientation of ongoing relative crustal motions between Eurasia and Africa plates. The Apenninic belt shows a diffuse extensional stress regime indicating a ~NE–SW direction of extension, related to a second-order stress field. The horizontal stress rotations observed in peculiar areas (see Emilia Romagna area) reflect a complex interaction between first-order stress field and local effects, revealing the importance of the tectonic structure orientations.

The existence of first-order stress field (plate-scale) controlled by plate boundary forces, and second-order stress field (regional) controlled by major intraplate stress sources, has been clearly demonstrated. In areas where high data density is present, a third order stress field (local) can also be recognized linked to the presence of minor features (i.e. active faults, local inclusions, detachment horizons or density contrasts). Such features may explain stress rotations that can be found not only between two adjacent wells but also in the same well along depth, as observed when fractures, active faults or mechanically weak zones are crossed by, or close to, a borehole.

The local stress orientations in some cases overrule the first- and second-order stress pattern: major discontinuities within a rock mass disturb the stress field causing localized increases in differential stress and an associated change in the orientation of the stress trajectory. The free surfaces of an open fracture in a rock body deflect stress trajectories in the closer surrounding area, so the smallest principal stress approaches the free surface at right angle. The stress field rotates in proximity to an active fault due to small slip increments on the fault, possibly induced by the tectonic movement or due to an increase of pore pressure on the fault when drilling through it. Stress rotations identified near active (or young) faults can be used to make assumptions about the strength of the fault zone compared with the surrounding rock mass. In fact shear zones usually show physical properties different from the nearby undamaged rock: these features can be recorded by downhole logs and then compared to stress data. On the contrary, if any stress perturbation occurs close to a fault, this latter can be considered a sealed fault with characteristics similar to the host rock body.



Schmitt et al., 2012

Cartoons of stress induced borehole deformation with the corresponding breakout zones and drilling induced tensile fractures (green) that are perpendicular and parallel to the SHmax orientation, respectively.

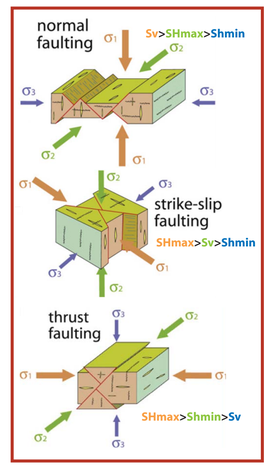
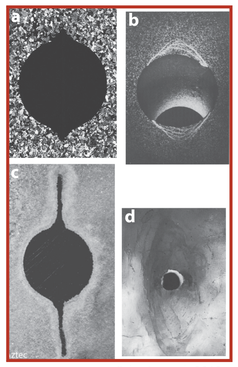


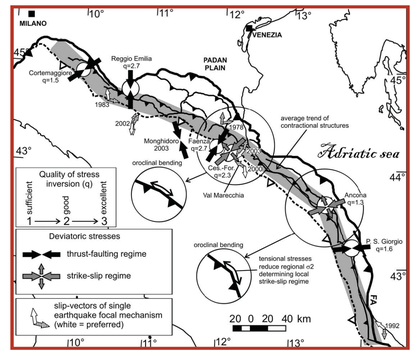
Illustration of the three pure reference stress states with SHmax, Shmin, and Sv with respect to σ1, σ2 and σ3, according to the Andersonian stress model (*Anderson, 1905*).



Schmitt et al., 2012

Examples of laboratory created breakouts from vertical boreholes: a) in a Westerly granite cube (Sh=50MPa, Sv=60MPa, SH=190 MPa); b) in an anisotropic Berea sandstone hollow cylinder subject to an external confining pressure of 75 MPa; c) in a porous Aztec sandstone (Sh=20MPa, Sv=30MPa, SH=45MPa), and d) a heated clear epoxy subject to a triaxial state of stress.

Stress rotations along the Padano-Adriatic belt



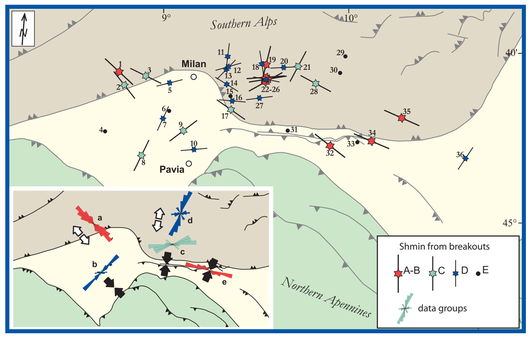
Boncio and Bracone, 2008

References

Anderson E. M., 1905 - Geological Society, 8, 387- 402.
Boncio P. and V. Bracone, 2009 - Tectonophysics, 476, 180–194, doi:10.1016/j.tecto.2008.09.018.
Mariucci M. T., A. Amato, R. Gambini, M. Giorgioni, and P. Montone, 2002 - Tectonics, 21(4), 1021, doi:10.1029/ 2001TC001338.
Barton C.A. and M.D. Zoback, 1994 - J. Geophys. Res., 99, 9373–9390, doi:10.1029/93JB03359.
Bell J.S., G. Caillet, and J. Adams, 1992 - Geol. Soc. Lond. Spec. Publ., 65, 211–220, doi:10.1144/GSL.SP.1992.065.01.16.
Emergeo WG, 2013 - Natural Hazards and Earth System Sciences, 13, 935–947, doi:10.5194/nhess-13-935-2013.
Mariucci M.T., P. Montone, and S. Pierdominici, 2008 - Ann. Geophys., 51(2–3), 433–442.
Mariucci M.T., P. Montone, and S. Pierdominici, 2010 - Geophys. J. Int., 182(2), 1096–1102, doi:10.1111/j.1365-246X.2010.04679.x.
Montone P., and M.T. Mariucci, 1999 - Geodynamics, 28, 251–265, doi:10.1016/S0264-3707(98)00041-6.
Montone P., M.T. Mariucci and S. Pierdominici, 2012 - Geophys. J. Int., 189, 705–716, doi: 10.1111/j.1365-246X.2012.05391.x.
Pierdominici S., M.T. Mariucci, P. Montone, and M. Cesaro, 2005- Ann. Geophys., 48(6), 867–881.
Pierdominici S., M.T. Mariucci, and P. Montone, 2011- J. Geodyn., 52(3–4), 279–289, doi:10.1016/j.jog.2011.02.006.
Schmitt D. R., C.A. Currie, and L. Zhang 2012 - Tectonophysics, 580, 1–26, doi:10.1016/j.tecto.2012.08.029.

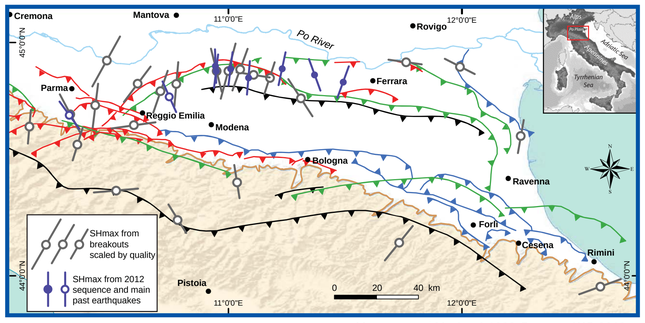
1 LOMBARDY

The results, in terms of Shmin orientations, show a very complex pattern characterized by inhomogeneous trends. The structural setting of the area consists of arc shaped thrusts and the results partly reflect this geometry.
In the inset, two main Shmin orientations are highlighted: the wells located near to the thrust front show directions parallel to it indicating an active compression; the ~N-S Shmin direction - confined farther from the thrust front - indicates the area where the active extension is prevalent. Moreover, these Shmin orientations have been found at different depths: NS breakout trend in the shallow part of the structures; whereas the E-W breeakout trend is predominant in the deeper part (below 2000 m).



Pierdominici et al., 2005

2 EMILIA-ROMAGNA

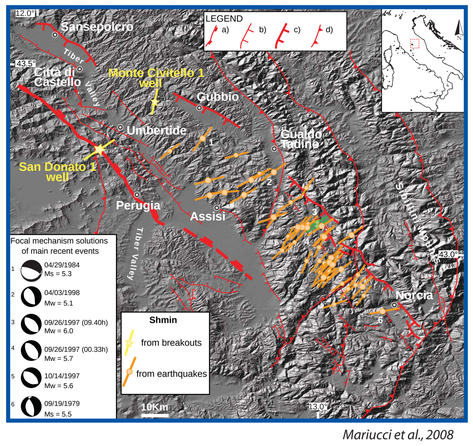


Montone and Mariucci, 1999; Emergeo WG, 2013

Along the Ferrara- Romagna Arc, the SHmax is clearly N-S oriented following the first-order stress field. The local SHmax rotations are linked to the curvature of active thrust fronts structures deflecting the regional stress.

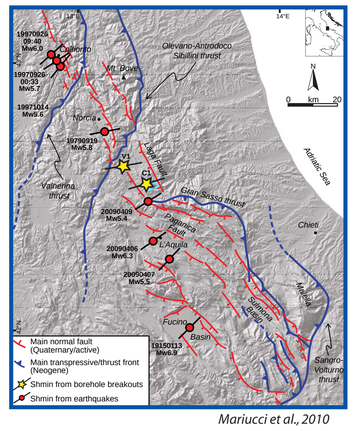
3 UMBRIA

The active stress field shows a prevalent NE-SW extension, perpendicular to the main tectonic structures, in agreement with the breakout results. San Donato 1 well shows a Shmin orientation consistent with both the regional and local trend. The Shmin orientation inferred from Monte Civitello 1, ~N-S, slightly differs from the regional trend suggesting the influence of active structures, such as E-W normal faults or strike slip faults perpendicular to the belt or N-S transfer faults.



Mariucci et al., 2008

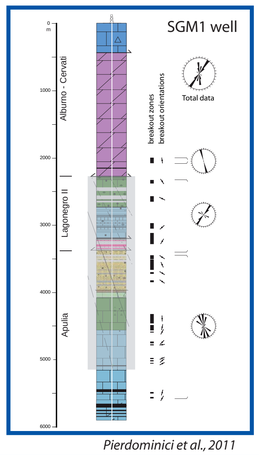
4 ABRUZZO



Mariucci et al., 2010

The breakout orientations in this area show a slight difference with respect to the NE–SW apenninic regional trend. **V1** Shmin orientation is controlled by the presence of ~N–S structures. The **C1** well - placed on the hanging wall of the Laga fault - shows a Shmin trend congruent with the NNW-fault orientation.

5 SOUTHERN APENNINES

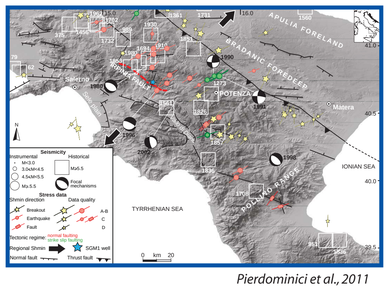


Pierdominici et al., 2011

San Gregorio Magno

In southern Apennines the stress field is well defined with an active extension NE-SW oriented. The stress analysis along the San Gregorio Magno 1 well (SGM1), indicates a quite consistency with the neighbouring regions.

Different breakout orientations are explained by the influence of nearby active faults on the local stress field.



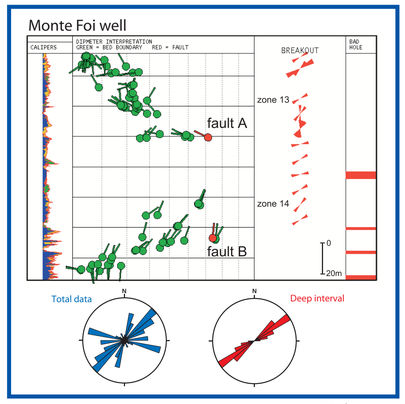
Pierdominici et al., 2011

Monte Foi

Example of breakout reorientation close to a fault zone evidenced by the comparison between structural analysis and breakout analysis based on dipmeter data.
Along this well, some stress perturbations have been identified associated to open fractures and to active faults which have slipped recently.

Active faults at depth are often identified also by downhole logs analysis because they show physical properties different from the nearby undamaged rock.

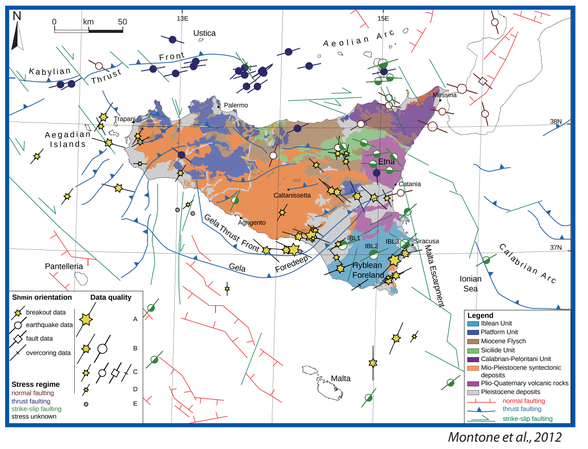
The rose plot (blue one) - relative to the total breakout data - is clearly influenced by the presence of several shear zones; in the deepest part - where the shear zones are absent- the breakout orient ations are consistent to the regional stress field (red plot).



Mariucci et al., 2002

6 SICILY

In Sicily, the alignment of horizontal stresses closely matches the ~N–S direction of ongoing crustal motions with respect to stable Europe. This result can be associated to the first-order stress field that drives the plate movement. In particular, in Sicily the data delineate a more complete tectonic picture highlighting adjacent areas characterized by distinct stress regimes. The small-scale changes in the stress orientations, and in some cases also in tectonic regime, over distances of a few tens of kilometres indicate complex tectonic processes and interactions amongst different stress field orders.



Montone et al., 2012