Stress Regime in Italy: State of the Art

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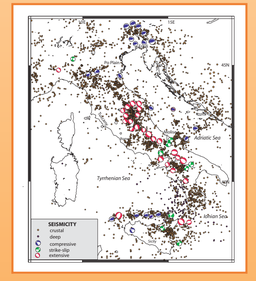
Abstract

Stress data collection and analysis in Italy increased a lot in the last decade but there is still a lot of work to be done. First of all concerning stress magnitudes: deep data are very few and an organized collection of shallow depth data is not yet available for scientific purposes, despite the large amount of shallow rock stress measurements. Stress magnitude data could contribute to deal with a wide spectrum of engineering problems but also to get reliable stress profiles from surface to earthquake depths useful for seismotectonic models. Here we present our latest work on stress magnitude determination inferred from more than two hundreds new leak-off test data from oil wells, kindly provided by ENI S.p.A (Italian Oil Company). We analyzed them notwithstanding the problems of the datum itself and did our best to obtain as much as possible reliable information on the state of stress of Italian peninsula. We calculated the values of the principal stress axis and stress regime at different depths, ranging from about 200m to 5000m, also considering the possible scattering of data and their uncertainties. We compared the results with horizontal stress orientations from borehole breakout analysis and other stress indicators. We analyzed the pictures of stress regime at different depths and along different transects through the Apennines, speculating about the reasons of regime changes that are observed in some areas. The state of stress depicted by the new data confirms the results of previous studies making them and the new ones more confident.

Introduction

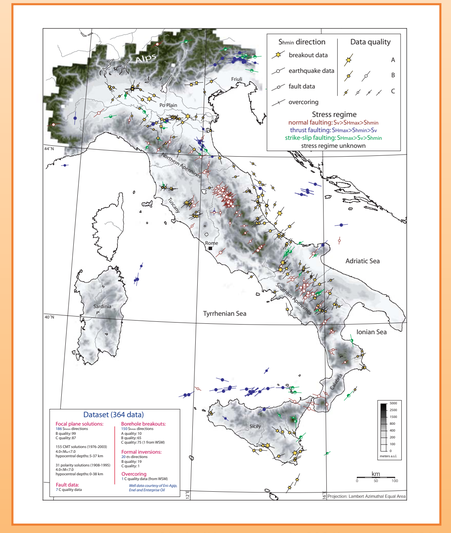
In Italy since seismicity is not homogeneously distributed and fault plane solutions are not available for all earthquakes, the stress regime is not well known everywhere. For a better knowledge of crustal stress, both at shallow depth and in low seismicity areas, we estimated the stress regime with different methods: the analysis of **leak-off tests** performed in deep wells, the **depth of borehole breakout occurrence**. An accurate knowledge of the present-day stress is important both for predicting which faults are more likely to slip and to model stress transfer among adjacent fault segments.

Seismicity and focal mechanisms



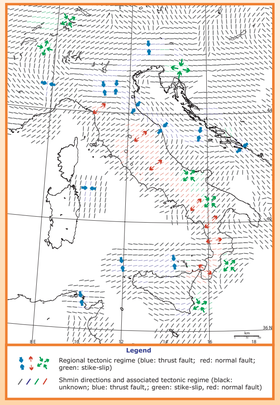
This map shows the seismicity distribution of M>3 earthquakes for the period 1983-2003 and the Centroid Moment Tensor fault plane solutions for M>5 (from INGV and CMT catalog).

Stress map of Italy



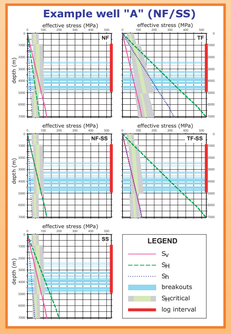
The present-day stress map of Italy (Montone et al., 2004) consists of 364 data of reliable quality according to the ranking of World Stress Map Project, mainly from **fault plane solutions** (185) and **borehole breakouts** (150). The data show a compressive tectonic regime in the northern Apennine front, from the Po Plain to the Adriatic offshore and along the southern Tyrrhenian Sea, north of Sicily. In the Alps both compressive and transcurrent regimes are observed. Our data also confirm that the whole Apenninic belt and the Calabrian arc are extending. Along the central Adriatic coast changes from one stress regime to another are shown by abrupt variations in the minimum horizontal stress directions. Other more gentle stress rotations, as for instance from the southern Apennines to the Calabrian arc, or along the northern Apennines, follow the curvature of the arcs and are not associated to a stress regime variation.

Stress directions and regimes



This smoothed stress map, constructed using the best active stress indicators, highlights large-scale patterns and removes local perturbations within the observed orientations. We applied a **smoothing procedure** due to Müller et al. (2003). The algorithm first places a regular grid over the study area, then calculates stress orientation for each grid point by considering data within a certain radius around the grid point itself. The data are weighted by their previously attributed quality and by the distance from the grid point. We have integrated our data set with part of the World Stress Map database taking into account 921 Shmin directions (only A, B and C quality): 362 from our data set and 559 from the World Stress Map database 2003 release for regions around Italy. In this figure we used a "search radius" value of 90 km, a degree of smoothing equal to 1 and only grid values with at least one data point of A or B quality (or two quality C data) inside the area defined by the "search radius".

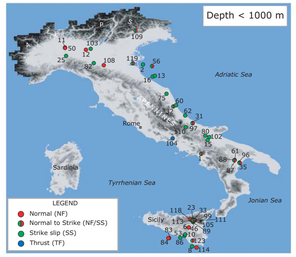
Regime from borehole breakouts



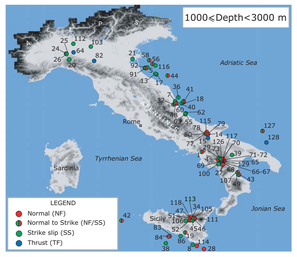
We estimated the stress regime in 20 boreholes from the comparison between the **depth of breakout occurrence** and the **physical properties of the rocks**. Assuming that: (a) one of the principal stress is vertical, (b) the state of stress is at the limit of the frictional equilibrium on pre-existing optimally oriented faults, and (c) the pore pressure is hydrostatic and equals the fluid pressure in the well, from rock strength and density, we can calculate the critical value of the maximum horizontal stress (SHcrit) for which the effective tangential stress at the borehole wall overcomes the rock strength and breakouts can develop. Since we can calculate a reasonable vertical stress, equal to the weight of overburden, we can determine the three principal stresses for each stress regime. Then, comparing the theoretical stress distributions with breakout occurrence, it is possible to infer the stress regime. We investigated boreholes, up to 6 km deep, located in different tectonic environments and characterised by breakout data of good quality (A, B and C, according to Word Stress Map quality ranking system).

We computed SHcrit taking into account the range between C_0 (uniaxial compressive strength) and C_b (biaxial compressive strength) and 30% of error on both values. Whenever the estimated maximum horizontal stress (SHmax) overcomes SHcrit we should observe borehole breakouts. Therefore, comparing breakout occurrence along the well with the principal stress magnitudes and the different SHcrit ranges for each stress regime, we can identify the most likely regime for the observed breakouts.

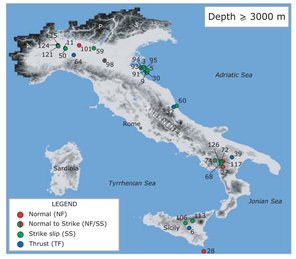
Stress magnitudes



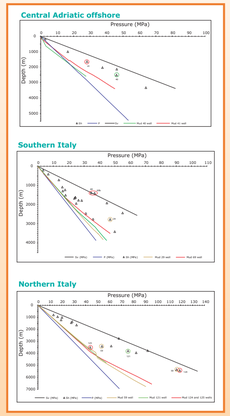
N	Depth	Regime	N	Depth	Regime
1	205	NF/SS	80	408	SS
2	797	SS	82	945	SS
6	913	NF	83	730	NF
8	705.9	SS	84	988	NF
10	445	SS	86	513	SS
11	632	SS	87	216	NF/SS
12	310	NF	88	730	SS/NF
13	990	SS	89	508	SS
15	320	SS	96	365	SS
16	922	SS	97	280	SS/NF
23	607	SS	99	272	NF
25	940	SS	102	367	SS
31	289	NF	103	405	SS
32	740	SS/NF	104	344	TF
33	411	SS	105	410	SS/NF
35	362	SS/NF	108	997	NF
46	412	SS	109	200	NF/SS
50	640	NF	110	715	SS
53	415	SS	111	415	NF
56	13	NF/SS	113	491	SS
60	160	SS	114	623	NF
61	766	SS	118	418	NF
62	603	SS	119	855	SS/NF
75	304	SS	123	659	SS/NF



N	Depth	Regime	N	Depth	Regime
1	1079	NF/SS	62	2210	SS
4	2278	NF	63	2544	SS
5	2030	SS	64	2744	TF
7	2563	SS	65	1908	TF
8	2570.4	SS	66	1527	SS
13	2130.1	SS	67	1544	SS
14	1622	NF	68	1715	TF
15	1010	TF	69	1387.5	TF
17	1643	SS	69	1391.5	TF
18	1121	SS	70	2187	SS/NF
19	1290	SS/NF	71	1405	SS
20	1009	SS	72	1936	SS
21	2278	SS	73	1973	SS
24	1310	SS	77	2430	SS
25	1625	SS	78	1676	NF/SS
26	1109	SS	79	1764	NF
27	1173	NF	80	1780	SS
28	2718	NF	82	1912	TF
29	2763	SS	83	1558	SS
32	2248	NF/SS	84	1459	NF
34	1555	NF	86	1297	SS
36	1042	SS	91	1500	NF/SS
38	1547	SS	92	1540	SS/NF
39	2286	SS	100	2672	SS
40	2508	SS	103	1200	SS
41	1637	SS/NF	105	1870	SS/NF
42	1737	SS/NF	106	2535.5	SS
43	1185	NF/SS	107	2015	SS/NF
44	1105	SS/NF	111	1373	NF
45	1287	SS/NF	112	1438	SS
46	1653	SS	113	2800	SS
47	1602	SS	114	2651.5	NF
48	1364	SS/NF	115	1511	NF
49	1228	SS	116	1207	SS
51	1487	SS	117	2460	NF
52	2394	NF	118	1769	NF
55	2543	SS	126	2070	SS
56	1330	NF/SS	127	1943	SS/NF
58	1305	SS/NF	128	1618	TF
60	2025	SS	129	2752	N



N	Depth	Regime
3	4096	SS
5	4300	SS
6	3017	TF
9	3860	SS
11	5344	SS
27	3458	NF
28	3300	NF
30	3936	SS
32	4559	TF
39	3335	TF
50	4483	SS
59	5344	SS
60	3326	SS
64	3769	TF
68	3195	SS
72	3308	SS
74	3027	SS
91	3057	NF/SS
93	3364	SS/NF
94	3805	SS
95	3381	SS
98	3816	SS/NF
101	3484	NF
106	3220	SS
113	3272	SS
117	3405	NF
121	3786	SS
124	5417	NF/SS
125	3509	NF
126	3375	SS



Leak-off tests (LOTs) are open-hole micro-fracs that are run as a safety measure to assess the level of fluid pressure that a well can sustain before its walls fracture. Leak-off pressure can be considered broadly equivalent to the minimum principal stress (σ_3). The vertical stress (Sv) is computed from density logs. If these values are close or equal, a thurst faulting regime can be supposed. In the other cases σ_3 corresponds to the minimum horizontal stress (Sh) and the maximum horizontal stress (SH) is computed, using the formula: SH= 3Sh - 2Po, where Po is the pore pressure from drilling mud weight (Zoback et al., 2004). We inferred the stress magnitudes and regimes by analysing 192 LOTs performed in 123 deep boreholes at depth between 160m and 5417m. Most results show strike-slip and normal regimes. The comparison of these results with fault plane solutions of crustal earthquakes is possible only in a few region. Some cases where LOTs point out a thrust faulting regime can be due to overpressure not taken into account due to lack of data. The leak-off analysis in the Adriatic off-shore shows that at depth of 2-3 km the stress regime is characterized by strike-slip regime.

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