STATIC STRESS CHANGES INDUCED BY THE MAGMATIC INTRUSIONS DURING THE 2002-2003 ETNA ERUPTION

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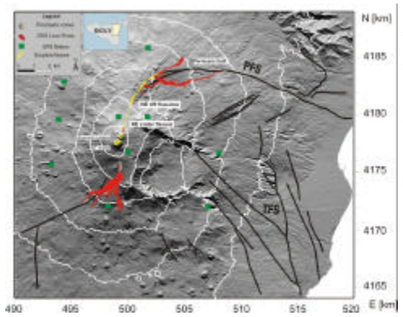
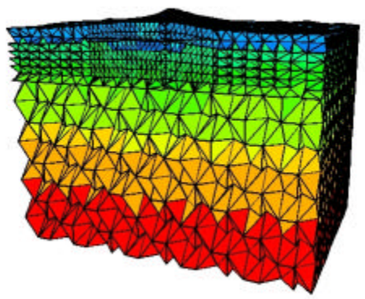
Introduction



The2002-2003Etnaeruptionoffersagoodcase studytogaininsightintothecomplexinteraction between magma intrusive events and tectonic responsebecause of: (i) the high-quality ground deformation data whose inversion allowed for a detaileddescription of the intrusive sources; (ii) the associated seismic activity recorded in the periodspanningtheintrusion.

During the night of 26-27 October 2002, the openingoftwoeruptivefracturesystemsonboth the NE and S flanks of Etna volcano was accompaniedandfollowed by anintenseseismic sequence mainly affecting the volcano's eastern sector.Mostoftheearthquakesduringthefirst hourstookplaceinthecentralupperpartofMt Etna,andaftermidnightmigratedinanortheast directioninvolvingtheNorthEastRiftandPernicanaFault. Inthefollowinghourstheeruptivefracturesystem openedonthenortheasternflank,nearlytotheNERift. Geodeticdatahavebeenalreadyinvertedtoimagethe observeddeformationpattern.Theinversionoftiltdataand GPShorizontalandverticalcomponents,recorded inthetimeinterval26-27Octoberspanningtheeruptiononset,requiredaverticaluprisingdikeinthesouthern flankandalateralintrusionpropagatingalongthenorth-easternsector.

NumericalModeling



In order to study in a morerealisticwaythe groundde formationsobservedonMtEtnaduring theonsetofthe2002-2003eruption,afully3D finite element model is carried out. We investigatehowtopographyandcomplex medium heterogeneity can affect the results. The modelingisconductedusingtheLithomopfinite elementcode.UsingLaGriT,a3Dgridgeneration code from Los Alamos National Laboratory (http://lagrit.lanl.gov),thecomputationaldomain was meshed into isoparametric tetrahedral elements. The source geometry and the dislocationparametersoftheintrusivedykesare basedontheresultsofgeodeticdatainversion. Inordertosimulatethetwodykeintrusionsweassigneddislocationboundaryconditionsimplementedusing "splitnodes" tothenodeslyingonthedykesurfaces.

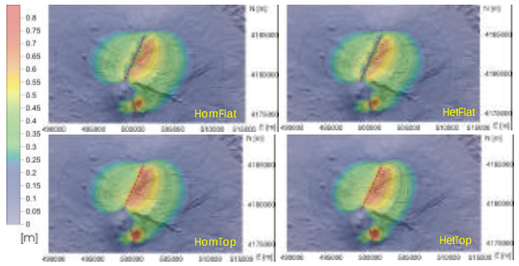
TheelasticparameterswereestimatedusingV_p andV_s wavevelocitiesinferredfromseismictomography. Thesubsurfaceelastictheterogeneitiesofthemediumwereincludedinthenumericalmodelbyassigningto eachelementinthemeshedddomainthevalueoftheelastic Young'smodulusinterpolatedatthelementlocation. A Poissonratioequalto0.25isassumedthatisareasonable approximation on Mt.Etna. Insuchacase,theYoung's modulus,E,isrelatedtomediumdensity ρ andseismicwave velocityVpthroughthefollowingrelation:

$$E = \frac{5}{6} \rho V_p^2$$

Usingamediumdensityof2400kg/m³ theYoungmodulus variesintherangefrom11.5GPaatshallowerdepthto133 GPaathigherdepth.

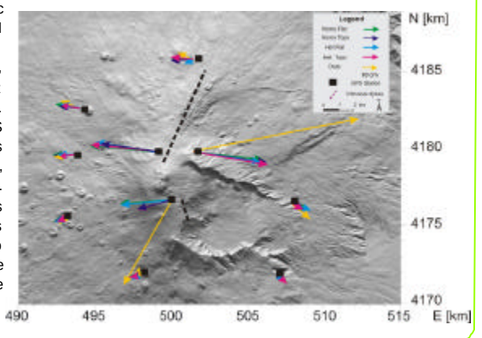
	Rift South	Rift North
X center [m]	499538.4	500682.1
Y center [m]	4175474.0	4181637.0
Depth [km]	2	0
Lenght [km]	1.5	7.8
Width [km]	1.6	3.1
Azimuth [°]	-17.2	23.3
Dip [°]	80.3	81.9
Strike Slip [m]	0.0	1.0
Dip Slip [m]	0.0	0.0
Opening [m]	1.5	1.0

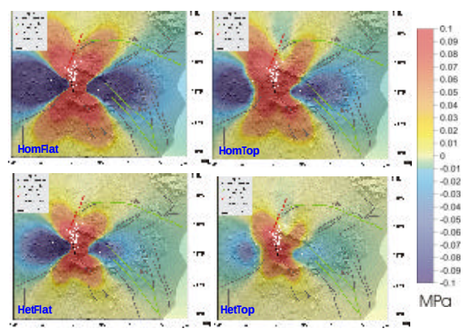
GroundDeformation



Discrepancieswithrespectto the analytical results are expected on ground deformationvaluespredicted by the numerical models because of the medium heterogeneity and the irregular topography of Mt Etna. Indeed, the volcano edificeisratherasymmetric having a prominent mass deficitintheeasternsector with respecttothewestern sector incorrespondenceof Valle del Bove. A good approachtoestimatehowmaterialpropertiesandtopographymayaffectthegrounddeformationistoevaluate eachoneseparatelyandcomparetheresults.Therefore, we conductfour numericalmodels in whichwe considered:(i)anhomogeneouselasticmediumwithaflatsurface(HomFlat),(ii)anhomogeneouselasticmedium withtherealtopographyofMt Etna(HomTop),(iii)anelasticheterogenousmediumwithaflat surface (HetFlat), (iv) an elastic heterogeneous medium with thereal topography(HetTop).

Tobetterappraisesuchperturbations, weevaluatedthedisplacementfieldat theGPScontinuouslyrunningstations. Figure shows the horizontal GPS component together with results achieved by HomFlat HomTop, HetFlat, HetTop numerical models. Discrepancies of few centimeters amonganalyticalandnumericalmodels are mainly restricted to thevolcano summit area because of the accentuated topography and the mediumheterogeneity.



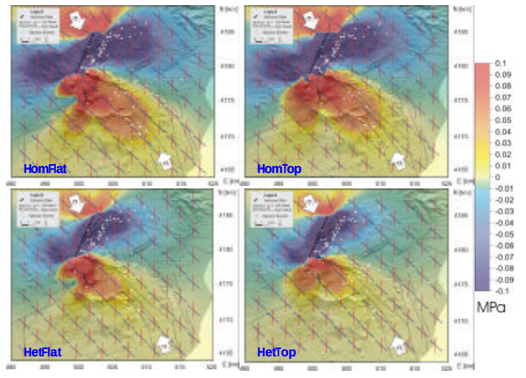


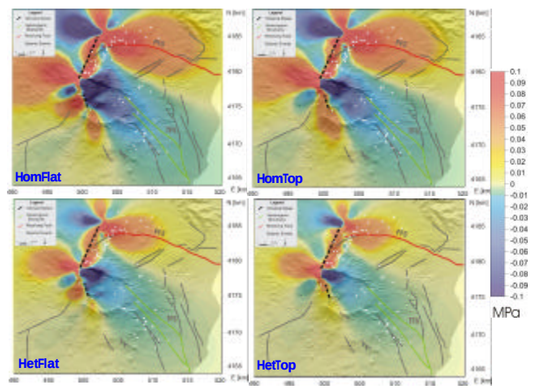
Stress Changes on RiftNorth

Tobetterunderstandtheinteraction between tectonic and intrusive processes, wefirstlyexamined the stresstransferassociatedwiththe SouthdykeintrusionontotheNorth East Rift. The horizontal normal stressontheNERiftisshownona map view computed at 1 km bsl. Besidestheamplitudeandtheshape ofstresspatterns,allthenumerical models show a positive stress changes. The HomTop and HetTop numericalmodelsshowhowthestress pattern isaffectedbytheMtEtna topography.Thepositivestresschangeinthenorth-eastareapointoutthattheverticaluprisingdikeinthe southernflankofthevolcanogeneratedanextensionalstressfieldwhichpromotedthelateralintrusion propagatingalongthepre-existinngcrustalfracturesystemoftheNERift.

StressChangesonPernicanaFault andTimpeFault System

Wecomputedtheinducedstressbymeansof Coulombfailure stresschangesdefinedby: $\Delta CFF = \Delta\tau + \mu(\Delta\sigma_n + \Delta P)$ where $\Delta\tau$ istheshearstressinthedirectionofsliponthe receiver fault, $\Delta\sigma$nis thenormalstresschange,m is the frictioncoefficientand ΔPistheporepressurechange. The changeinporepressureisgivenas: $\Delta P = -B\frac{\Delta\sigma_{kk}}{3}$ where $\Delta\sigma_{kk}$ isthevolumetricstressandBistheSkemptoncoefficient. Weresolvedthestresstensorgeneratedbybothsouthern and northern dike intrusions onto the optimally oriented strike-slip faults and mapped structural trends of the Pernicana Fault (PF) and Timpe Fault System (TFS). We computed theoptimallyorientedplane(OOP)followingKinget al.(1994).Usingasfortheregionalstressfield a horizontal σ_1,orientedN337°,weobtainanOOPwithorientationsranging from N340°toN20°foraleft-lateralstrike-slipfaultand N110°toN157°foraright-lateralstrike-slipfault.





TheruptirealongtheTFSisoptimallyorientedwhilethePF isnotoptimallyoriented. Insuchstructurallycomplexareas, it is advisabletoresolvedirectlythestressfieldontothe mappedstructuraltrends.Therefore,weresolvedthestress changes, generated by the southern and northern dike intrusions, onto a vertical planeoriented N100 withleft lateralmotionforthePFandontoaverticalplaneoriented N145 with right lateral motion for the TFS. The maps emphasizethecleardifferencebetweenthe ΔCFFresulting fromresolvingstresschangesontothePernicanafaultplane inferred from geologicalstructural constraints and that resultingfromOOPs.TheCoulumbstresschangedecreases from0.8MPaforthehomogeneousmodels(HomFlat and HomTopo)to0.6MPafortheheterogeneousmodel(HetFlat andHetTopo),whichgivesadifferenceof0.2MPainthemost westernpartofthe PF.The ΔCFFresolvedontotheTFSis quitesimilartothatresultingfromOOPs;inallthenumerical models, the TFS is encouragedto slipanditisoptimally oriented.

The ΔCFF resolvedontotheTFSisquitesimilartothat resultingfromOOPs;inallthenumericalmodels,theTFSis encouragedtoslipanditisoptimallyoriented.Computations of Coulomb stress changes show that seismicity well matchesareasofincreasedstaticstresschangescausedby the intrusive eventalongthesouthernandnortheastern flanks. Extension along the North-East Rift zone was followedbytheleft-lateralmovementofthePFandthe right-lateralmovement along the TFS.The presence of mediumheterogeneitystronglyaffectstheamplitudesof thestaticstresschanges.Sincerecentstudiesonstress triggeringeffectspointoutthatafewbarscouldincrease ordecreaseseismicity in faultareas, the assumption on medium properties is a crucial point. Particularly, the HetToponumericalmodel,whichincludesthetopography andmediumheterogeneity,predictsstaticstresschanges ofafewbarsforbothThePFandtheTFS. Thisisan indication that the structureswerealready in a critical stateandtheeruptionhasadvancedtheoccurrencetimeof faultruptures.