Periodic technical report

Part B

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Project [1] Number: [727550]

Project Acronym: [GEMex]

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Work package 1

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Executive summary

This report gives an overview over the project activities performed in the first reporting period, which covers the period from 1st October 2016 to 31st March 2018. It provides a detailed description of the actions taken and the results obtained so far. Deviations from the Description of Action in the Grant Agreement are highlighted for each work package, as well as dissemination activities and publications. The status of all work packages is reported and the links to the milestones reached and deliverables already submitted or in preparation are shown.

GEMex is a joined effort of the European project (funded by the European Union's Horizon 2020 programme for Research and Innovation under Grant Agreement No 727550) and the Mexican partner project (funded by the Mexican Energy Sustainability Fund CONACYT-SENER, project 2015-04-268074). This project report focusses on the European part, but since the two project are strongly connected, sometimes depending on each other and in all aspects collaborating, a strict distinction between activities performed by the Mexican or European colleagues is sometimes difficult. Consequently, this report will at some parts refer to the work performed by the Mexican team.

The general status of the project is: ***project is on track***. Currently, we do not anticipate any delays for the upcoming deliverables. The project experienced some delays at the beginning, which were mostly caused be the late provision of funding to the Mexican partner project and the missing permission for geophysical exploration at the Acoculco geothermal site. As a consequence, the project coordinator requested a project amendment which included the readjustment of due dates of a number of deliverables and milestones. This amendment was accepted by the European Commission and as a consequence we will now be able to reach all deliverables within the new timeframe.

Thanks to the great dedication and engagement of the consortium, significant progress was made towards the achievement of the objectives of GEMex. All work packages have successfully started their work. The main achievement can very roughly be summarized as follows:

- The management of the project (WP1) is ongoing and has set the boundary conditions for a successful implementation of the project activities. Most significantly, a close cooperation with the Mexican partner project has been encouraged and very good communication with the Mexican GEMex consortium is continuously sustained.
- The dissemination of project results and internal communication (WP2) has been enabled and supported. Various channels of dissemination have been used to reach different target groups. Internal communication has been supported by the Virtual Research Environment, which is used by both, the Mexican and the European consortium.
- The resource assessment (SP1; WP3 and 4) has been started and a lot of activities, which build the basic geological knowledge on the two research sites, have been carried out. Several fieldtrips were dedicated to collecting new data and take rock, fluid and gas samples. Preliminary geological and volcanological models have been developed. The knowledge gained in this part of the project has been presented to the project partners, which will subsequently make use of the results achieved so far. The geological fieldwork as well as the modelling were both performed in collaboration with the Mexican team in an equal partnership.

- The reservoir characterization (SP2; WP5 and 6) has started and the necessary data are currently collected. Geophysical fieldwork in Los Humeros is currently ongoing: some data has been collected already by all geophysical methods foreseen, the survey planning for the completion of the measurements is finished, data collection will be finished within 2018 and data analysis is ongoing. Sample analysis for physical rock properties is ongoing such that this data can contribute to the reservoir model to be established in WP6. Geophysical fieldwork has benefitted from enormous support by the Mexican team, who did the major part of the geophysical field surveys, even though survey planning and data analysis are carried out in an equal partnership.
- The concept development (SP3; WP 7 and 8) is still at the beginning and has mainly undertaken a literature review to analyse the state of the art, as well as acquisition of already existing data. Additionally, the work on social acceptance and public engagement has already started and collaboration with the Mexican team is very good, which is a prerequisite for this very sensitive part of the project activities.

Explanation of the work carried out by the beneficiaries and overview of the progress

This section describes shortly objectives of the project and gives a detailed insight into initial achievements and results from various activities implemented in individual tasks within all nine work packages of GEMex from the first 18 months of the project.

1 Objectives

GEMex is based on the assumption that the development of hot-EGS and SHGS resources carries an enormous potential to expand the known geothermal resource base and to multiply its energy output. Thus the overall objective of GEMex is to show a way how to better understand, explore and develop a) EGS in a hot geological environment and b) super-hot resources that cannot be explored and exploited by standard technologies.

The objectives for GEMex follow from the barriers and challenges identified for hot-EGS and SHGS resources. These include:

- To speed up the geothermal development in Mexico and beyond, by leveraging the knowledge of European and Mexican researchers and industry
- To reduce pre-drill mining risk by in depth understanding of the geological context of the resource, in order to improve prediction of the occurrence of geothermal resources and their quality
- To improve geophysical imaging and detection of deep reservoir structures by novel approaches dedicated to HOT-EGS and SHGS, and targeted to improved imaging resolution
- To improve predictive models for reservoir characterisation and simulation
- To provide conceptual models for sustainable site development

2 Explanation of the work carried out per WP

2.1 Work Package 1: Project Management

Lead: GFZ
Partners: CNR, GFZ, ISOR, TNO, UNIBA
Duration: month 1-44
Status: started and ongoing

Objectives:

The main objective of this work package is to properly coordinate and manage the legal, financial and administrative issues associated with GEMex and to ensure effective communication between the partners, the European Commission and all interested parties. This WP also encompasses the coordination with the Mexican partner project as well as the management and monitoring of deliverables and the planning, organising and implementing of Executive Board meetings.

An additional objective of the work package is the adjustment of the projects efforts with regard to the scientific aims and the summary of the results from the technical work packages towards the overarching project results.

Participant number	1	2	3	4	7	**Total**
Short name	GFZ	ISOR	TNO	UNIBA	CNR	
PM foreseen in total GEMex	36	4	4	4	1	49
PM used	13.5	3.3	1.9	2	0.5	21.2

Table 1: Status quo of personal resources WP1

Summary (incl. exploitable results and theirs exploitation):

The project management has been concentrating on coordinating different tasks and internal communication in order to implement the action according to the description of action. All the legal, financial and administrative issues of the project have been supervised and carried out accordingly. The communication with the Mexican partner project as well as the CFE (who holds the concessions for the two geothermal sites investigated in the project) has been a major task in the work package.

Scientifically, recommendations have been given to the technical work packages with regards to detailing of project plans. Two scientific workshops have been organised: The first workshop in June 2017 in Morelia (Mexico) was organised jointly with the Mexican partners and CFE to discuss in detail the project goals and to identify overlaps between the project goals and the interests of CFE in order to join the efforts. The second workshop was conducted in January 2018 in Potsdam (Germany) to specify the activities leading to the concept for EGS (WP7) and identify the best location within the Acoculco caldera. Both meetings were attended by EB-members and some WP-leads.

No deviations from the Description of Action have to be reported.

2.1.1 Task 1.1 Legal Issues

GEMex received a solid legal base as the consortium agreement was prepared by GFZ, negotiated with all beneficiaries and, finally, signed by all beneficiaries. Additionally, the coordinator negotiated a "Collaboration and confidentiality agreement" between the European Consortium and the CFE, who holds the concession for the two geothermal sites under investigation in GEMex. Negotiations were finished in March 2017 and the agreement was finally signed by all beneficiaries in August 2017.

The coordinator has been providing comprehensive advice on the legally correct implementation of the action to the consortium on various occasions.

Due to various changes occurred on the project, which were mainly caused by problems in the cooperation with the Mexican side and by the missing permission for geophysical exploration of the Acoculco site, and which affected the DoA and the financial aspects of GEMex, the coordinator supported the partners while preparing and submitting the first amendment to the Grant Agreement in 2018.

2.1.2 Task 1.2 Financial issues

The partners have been constantly informed on the financial issues and given advice when needed. The pre-financing from the European commission was distributed among the partners according to the consortium plan specified in the Consortium Agreement. A rough financial overview over the financial status has been achieved with the interim reports collected every 6 months and partners have been notified if their costs so far seem unusually high.

2.1.3 Task 1.3 Administrative issues

The coordinator has been in constant contact with the partners, providing them with administrative notifications via various mailing lists and exchanging individually on upcoming deadlines, activities or events.

The consortium agreed to submit interim reports always before (interim) project meetings. The coordinator has collected interim reports from all beneficiaries every 6 months which include a rough description of actions performed, publications, dissemination activities, collected data and delays with respect to the description of action. All beneficiaries have contributed to interim reports.

2.1.4 Task 1.4 Meetings

Project meetings are foreseen approximately every 6 months in order to encourage communication between the project partners and to facilitate the planning of joint tasks and the exchange of results. Table 1 details the planned and already carried-out project meetings.

Event	Location	Planned Date	Organizer
1st project meeting: Kick-off meeting (Joint meeting with Mexican partners)	Morelia (Mich.), Mexico	15.-17.11.2016	UMSNH
2nd project meeting: European project meeting	Utrecht, The Netherlands	23.-24. 3.2017	TNO
3rd project meeting: General Assembly (Joint meeting with Mexican partners)	Akureyri, Iceland	2.-3. 10. 2017	ISOR / GFZ
4th project meeting: European project meeting	Bari, Italy	12.-13. March 2018	UNIBA
5th project meeting: General Assembly (Joint meeting with Mexican partners)	Morelia (Mich.), Mexico	October 2018	UMSNH
6th project meeting: European project meeting	Bochum, Germany	Mai 2019	HBO
Final conference and General Assembly (Joint meeting with Mexican partners)	Potsdam, Germany	February 2020? *tbc*	GFZ
Mexican final meeting	Mexico	Aug/Sep 2020	UMSNH

Table 2: List of project meetings

All project partners contributed to the project meetings. At all project meetings an Executive Board meeting took place. An exceptional Executive Board meeting was organised on 26 Jan 2018 on the precise planning of the project activities with regard to the project site in Acoculco in connection with the scientific workshop.

Additionally, virtual Executive Board meetings have been implemented whenever need arose.

- 30 Jan 2017 on various issues concerning the synchronisation with Mexican partner project
- 5 May 2017 on preparation of GA in Iceland and workshop on corrosion in Mexico as well as update on Mexican project status
- 10 Aug 2017 on possible change of project site for EGS
- 28 Aug 2017 on financial situation of Mexican partner project
- 5 Dec 2017 on next steps concerning the project site in Acoculco

Meetings with the Mexican coordinator are specified in the report on Task 1.6 *Communication with Mexican partners*.

Stakeholder Board meetings have been organised by partner EGEC and are reported in Task 2.5 *Events*.

2.1.5 Task 1.5 Deliverables to the European Commission

All Deliverables to the European commission which are scheduled for the first reporting period have been delivered. The first few deliverables have been withdrawn in June 2017 in order to reset them in the project template. No modifications to the content have been made, only to the format.

The Project Management plan with a detailed Gantt chart and a Work Breakdown Structure was delivered in D1.7 Project Management Plan.

All public deliverables have been published on the project website once they have been accepted by the Project Officer of INEA.

2.1.6 Task 1.6 Coordination with Mexican Partners

The coordinator ensures continuous communication with the Mexican partner project. The Mexican partners have access to the internal website VRE and the documents exchanged therein. The Mexican coordinator has participated in all project meetings so far and has a permanent guest status in the Executive Board. Therefore, the Mexican coordinator did participate in most of the Executive Board meetings specified in the report on Task 1.4 *Meetings*.

Additionally, several skype-meetings have been conducted. Here we summarize only the most important ones:

- 24 Mar 2017 joint meeting with PO Daniel Maraver on the delayed distribution of Mexican funding
- 18 Jul 2017 meeting on changes made to the Mexican project plan
- 22 Nov 2017 joint meeting with Task 7.4 and CFE on social work in Mexico

Organisational requests from the Mexican coordinator have been communicated to the project partners.

Apart from the official communication through the coordinator, all work-package leaders and most task leaders have been in close contact with their Mexican counterpart in order to ensure joint activities and the syncronisation of the two projects. The organisation of joint field-trips was the most important point up-to now, as well as the close collaboration in WP3 and 4 for the first version of geological, volcanological, and thermal models.

Two project meetings have been implemented jointly with the Mexican partners, namely the Kick-off meeting in Mexico in Nov 2016 and the General Assembly meeting in Akureyri (Iceland) in Oct 2017. All Mexican WP leaders and most of the task leaders have attended the joint meetings.

2.1.7 Deviations from the Description of Action

No deviations from the Description of Action have to be reported.

2.2 Work Package 2: Dissemination

Lead: CNR
Partners: CNR, EGEC, GFZ, IGA
Duration: month 1-44
Status: started and ongoing

Objectives:

Work Package 2 is ongoing and will follow the course of the GEMex project up to the end. WP2 is setting up the dissemination strategies and the tools to ensure a fruitful cooperation with Mexico on geothermal energy, to facilitate internal communication within the project consortium and external with the interested stakeholders. The dissemination of the project results has already started by means of different channels implemented in the 5 tasks and it will continue in the next months with the new foreseen tools. The objectives already achieved in each task are reported in the next subsections and the activities are detailed in the task reports.

Participant number	1	6	7	22	24	Total
Short name	GFZ	RWTH	CNR	EGEC	IGA	
PM foreseen in total GEMex	4	0	13.5	5.5	2	25
PM used	1.7	0.24	7.6	3.05	0.5	13.1

Table 3: Status quo of personal resources WP2

Summary (incl. exploitable results and theirs exploitation):

In the frame of WP2 was delivered a report on the Strategic and communication plan. This deliverable is currently at the second version and it is working as handbook to implement the strategies to communicate within the consortium and to engage stakeholders in an effective way.

The website (D2.2) is online since the end of December 2016 and since July 2017 is equipped with traffic tracer which provides as statistic dashboard in the backend. In 9 months, we have had about 1630 connections, 9988 page viewed and more than 30 users per week in average. Most of the clicks came from Mexico (15%) and Germany (13%), the most viewed page is the home page, but in the last weeks also the pages dedicated to the events (e.g., 1st side event and the GeoTherm 2018) has had a valuable score.

To share and make available the data produced by the GEMex project an Open Access Database and a report (D2.3) to describe its scope and operation were released. The database has to be enlarged with all the datasets in production in the different WPs. It currently includes many datasets related to the sampling locations. In particular, structural stations collected during 3 different field work, geochemical sampling points, petrophysical sampling points and CO2 flux measurement points are already stored, catalogued and made available as webGIS map.

Although many activities related to the other WP2 products has started, the connected deliverable are foreseen for the last months of the project (e.g., D2.4, D2.5, D2.6, D2.7 and D2.8).

The progress of the activities (i.e., achievement of the foreseen Milestones and release of the due deliverables) and the resources used are in line with the timing and effort/cost proposed in the Grant Agreement (GA).

The collaboration between work package leader, task leaders, project coordinator, WP2 participants, and the WP/task leaders of other work packages is very good.

No deviations from the Description of Action have to be reported.

2.2.1 Task 2.1 Strategic Communication Plan and communication campaign

This conceptual and organizational task is continuously ongoing. The plan for dissemination was arranged by CNR with the contribution of EGEC, GFZ and IGA at the beginning of the project. The plan provides different parts to spread the project information and results to the identified target groups. The dissemination plan also describes the main key messages and communication channels and tools in use and foreseen. A stakeholder map was prepared and the report includes an appendix on events planned. The events are organized by typology (e.g., project events, scientific events, stakeholder events and informative events for stakeholders, workshop for consulting stakeholders), date, GEMex implication, event name and the location.

The Strategic communication plan was implemented by CNR and described in the report D2.1 (https://goo.gl/Q3YGyT). A first version was finished in month 10. In month 18 the Strategic communication plan was revised by the WP2 participants and released as second version.

A stakeholder platform campaign and a stakeholder board were organized (and are reported in detail in Task 2.4).

The project branding, which includes logos and document and presentation template, was successfully developed.

2.2.2 Task 2.2 Website

The project website was designed and implemented by CNR within the first three months of the project: http://www.gemex-h2020.eu. It represents the D2.2. The website includes information on the project as well as all the publications and events regarding GEMex.

In the publications section, the references provided by the project participants are listed and their related file (if publically available) is linked for download. The events section publishes all the presentations in which GEMex project was described. The project report section lists all the deliverables with different colour on the basis of their status (i.e., green=delivered, orange=under delivering and white=to be delivered). A page reporting the links to the most important geothermal projects recently funded by the EC is available.

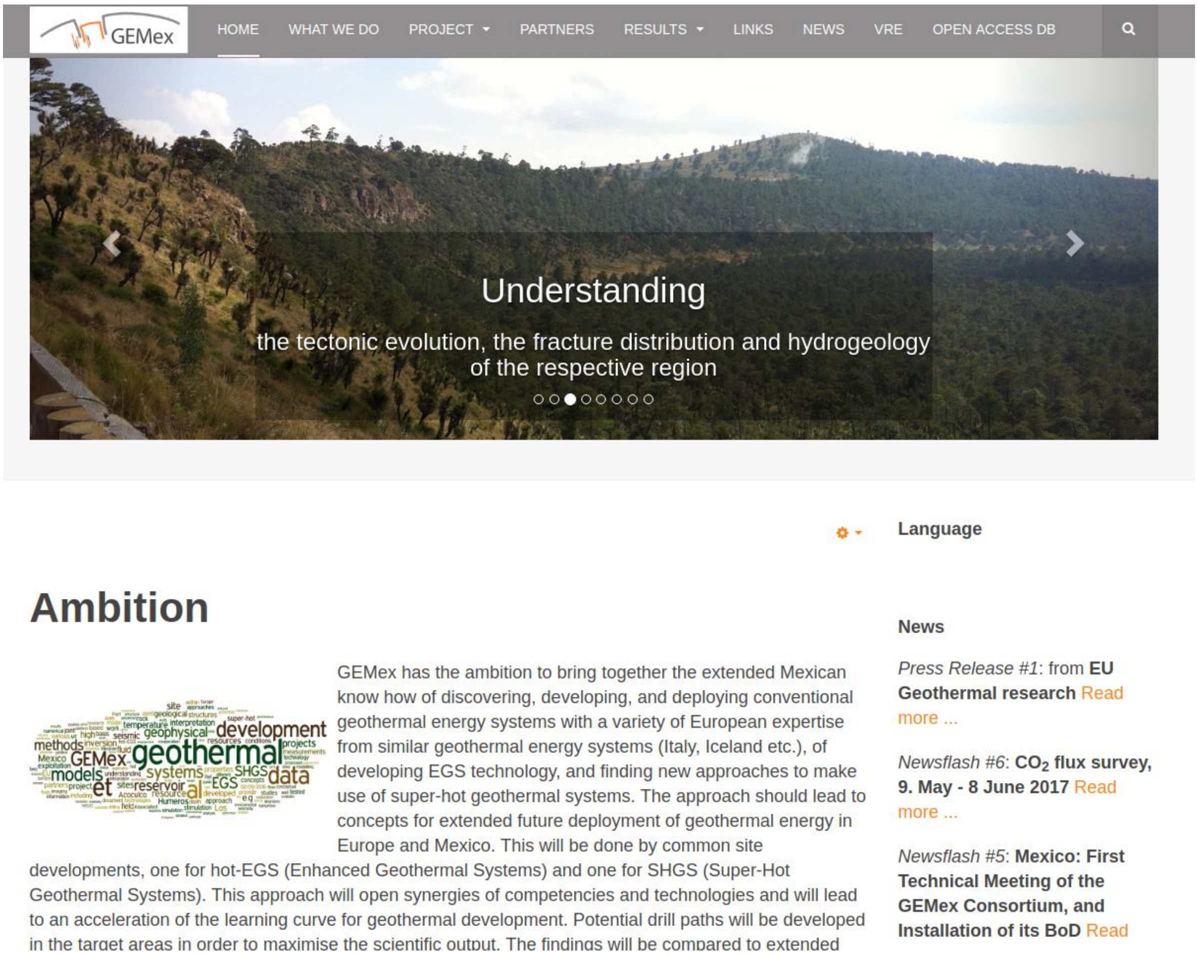

Figure 1: Website homepage

The website will be continuously updated up to the end of the project.

The administration part of the website is equipped with a statistical tool able to report the website traffic in the form of charts and analytic reports.

The Mexican WP2 counterside set-up a Spanish version of the website (www.gemex-h2020.mx) which is continuously synchronised with the English version and vice versa in a joint effort.

The private part of the project website, dedicated to the project consortium (Partner's Corner), was realized by using the Virtual Research Environment (VRE) technology based on an e-infrastructure provided by D4science.org organization. In the VRE a Shared Workspace acts as data repository where a remote, redundant file system is able to store data in different format and size in a system of folders that can be shared among the community. The VRE includes also a social networking facility allows the community to interact, share documents such as info, photos and data. The VRE is very well used by the project partners. Most important administrative (e.g. minutes from meetings and virtual meetings) and scientific documents (field reports, presentations, publications (drafts and published) are shared via VRE platform.

2.2.3 Task 2.3 Open access database

For Task 2.3, CNR has set-up an Open Access Database (OADB) to collect, describe and display the GEMex geothermal data, in the form of maps, datasets and information on models. Currently all stored data are catalogued and provided as interactive maps in a WebGIS.

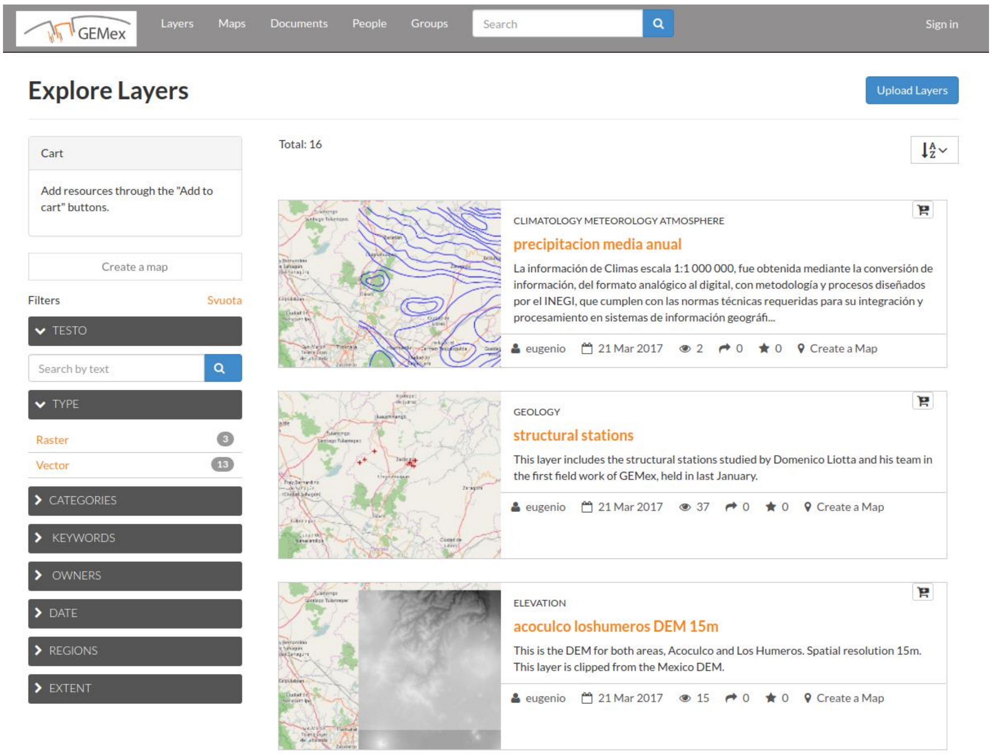

Figure 2: Open Access Database - List of available layers

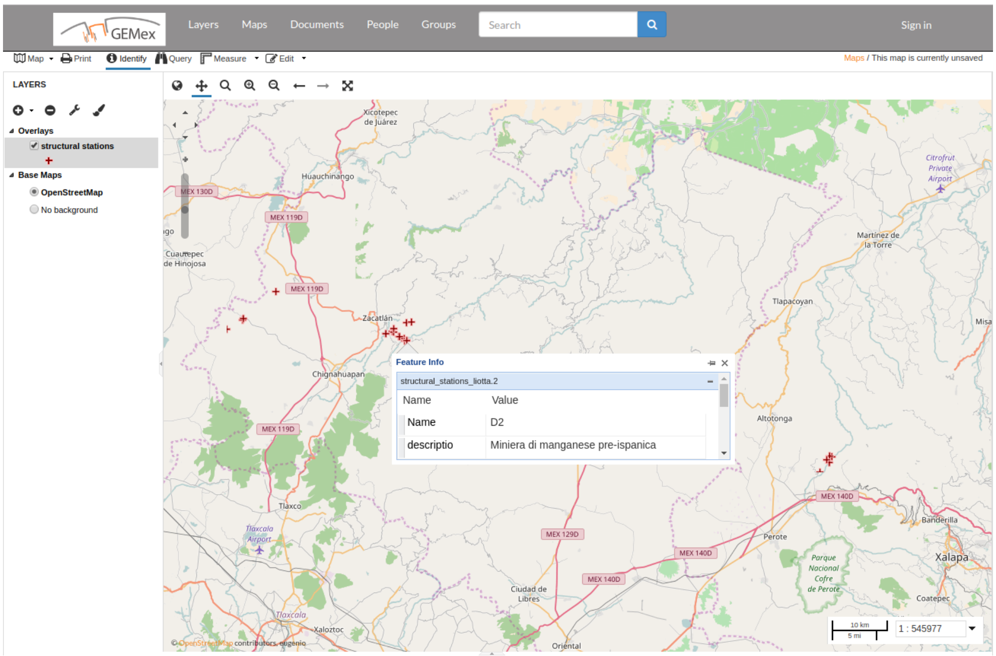

Figure 3: Open Access Database - WebGIS tool

The Open Access Database relies on GeoNode software, which allows to organize and display data in agreement with the main international standards and protocols.

CNR produced the D2.3 that includes the description of the GEMex Open Access Database implementation and the collection of data. Part of this report is in the form of a handbook to help user to access the available information.

Currently the OADB includes 21 spatial layers. All the layers are described with metadata in compliance with INSPIRE (i.e., standard ISO19139) and made available for the download in different file format. The layers are viewable in a webGIS interface embedded in the OADB. The uploaded layers include some general dataset made freely available by the Mexican authorities (e.g., DEM, a vectorial geological map, some geological important sites, caldera points, ...) and the locations of the sampling sites recorded by the GEMex scientists during the field works performed during this period. A dedicated map groups all the different sites represented by a different symbology.

The database is available by a dedicated link in the project website. It will be updated continuously with the datasets produced by each partner up to the end of the project.

2.2.4 Task 2.4 Promotion of project results

This task started in month 1 and is continuously ongoing. Task 2.4 aims at organising and generating the publications to promote project results. The planning and organisation of these publications is presented in the GEMex Strategic Communication Plan (Task 2.1).

The activities and publications foreseen for the promotion of project results are detailed, and closely linked, to both to T2.1 and T2.5.

Firstly, the release of the first e-news, foreseen for M18, has been shifted due to a delay in project results and it is now foreseen for M24. In the meanwhile, the main dissemination channels have been established (Mailchimp account and newsletter lists), including a list of more than 4000 stakeholders fitting the target audience for dissemination. Subscription to the distribution list is free and open to everybody through a signup form on the GEMex website. The distribution list is also used for dissemination of GEMex events and related activities.

Secondly, the GEMex brochure is planned around months 36-39.

Thirdly, a first draft of the Action Plan EU-Mexico, which aims at assessing barriers and best practices for geothermal development in Mexico, has been presented in project meeting n°4 in Italy and discussed with project partners. A table of content organising this action plan was already agreed, during the 3rd project meeting in Iceland, particularly with partners from T7.4, with which the deliverable is closely linked. The Mexican consortium also commented it. The presentation of the first draft of the Action Plan has accomplished the milestone MS9.

Fourthly, promotion of project results and activities is ongoing through the EGEC monthly newsletters, and during ETIP-DG meetings and newsletters.

Publications are already available (see Publications at the end of each WP report), but we expect that the submission of scientific and technical publications will mainly be addressed in the second part of the project once more results will be available.

The task has also contributed to the establishment of a network of stakeholders interested in project results. A database of more than 4000 contacts was established for GEMex project results dissemination.

Moreover, a call for interest for participation in the activities of the GEMex Stakeholders Board has been circulated in April 2017 and has led to the establishment of a Board comprising of 15 members. The Board held its first meeting on November 15th, 2017, in Brussels, Belgium (see T2.5). Interested stakeholders can submit their application to be part of the Board by sending an email to info@gemex-2020.eu

A project flyer was designed and approximately 300 flyers have been distributed up to now.

Finally, project activities and first results have been presented to the public in several conferences and meetings (Table 4)

Event	Location /Date	Who	Authors, Title
EGU 2017	Vienna (Austria)	Cesare Comina (UNITO)	C. Comina et al.: "A multidisciplinary approach for the characterisation of fault zones in geothermal areas in central Mexico"
GeoEnergi2017 – Geothermal Conference	Bergen (Norway), 22-23 May 2017	Walter Wheeler (CIPR)	W. Wheeler et al.: "GEMex- Europe-Mexico collaboration for development of Enhanced Geothermal Systems and Superhot Geothermal Systems"
		Jiri Muller (IFE)	Muller, J., "Laboratory Studies of Geothermal Tracers at Supercritical Conditions."
IAVCEI Conference	Portland (USA), 14-18 Aug 2017	G Gropelli	Groppelli, G., et al., "New geological, structural and volcanological data of the Los Humeros Volcanic Complex: implications for reconstruction of the 3D model volcanic structure and geothermal exploration."
German Geothermal Congress; Keynote lecture	Munich (Germany), 12-14 Sept 2017	David Bruhn (GFZ)	GEMex: Cooperation Europe-Mexico for the development of unconventional geothermal systems
IMAGE Final Conference	Akureyri (Iceland), 4-6 Oct. 2017	Anna Jentsch (GFZ)	Structural-geological impact on soil gas composition at Los Humeros Volcanic Complex

		Tania Toledo (GFZ)	Seismic network survey design and performance
5th European Geothermal Workshop	Karlsruhe (Germany), 12-13 October 2017	Leandra Weydt (TUDA)	Weydt, L., Bär, K., Sass, I. (2017): Outcrop Analogue Study to Determine Petrophysical Properties of the Los Humeros and Acoculco Geothermal Systems, Mexico
Stanford Geothermal workshop, Presentation on GEMex	Standford (USA), Feb 2018	Egbert Jolie (GFZ)	E. Jolie et al.: GEMex –A Mexican-European Research Cooperation on Development of Superhot and Engineered Geothermal Systems
European Geothermal PhD Day	Zurich (Switzerland), 14-16 Mar 2018	Tania Toledo (GFZ)	T. Toledo et al.: "Experimental Network Design for Earthquake Location Problems: application to geothermal field seismic networks"
		Baptiste Lepillier (TU-Delft/GFZ)	B. Lepillier, R. Bakker, D. Bruhn: "Characterization of a fracture-Controlled Enhanced Geothermal System (EGS) in the Trans-Mexican-Volcanic-Belt (TMVB)"
		Emmanuel Olvera-García (UNIBA)	E. Olvera-Garcia: "The Las Minas exhumed geothermal system (Veracruz, Mexico): a proxy for Los Humeros geothermal field"
		Gergö Hutka (GFZ)	Hutka GA, Hofmann H, Farkas MP, Yoon JS, Zimmermann G, Zang A, "Benchmarking of hydro-mechanical coupled models against true-triaxial laboratory hydraulic fracturing experiments"
Seminar	Universidad Politecnica de Catalunya (UPC-IDAEA-CSIC), March 15th 2018	Francesco Parisio (UFZ)	Parisio, F., "Enhanced supercritical geothermal systems: toward stimulation design"
EGU 2018	Vienna (Austria), 9 -13 April 2018	Leandra Weydt (TUDA)	L. Weydt, K. Bär, I. Sass: "Outcrop analogue study to determine reservoir properties of the Los Humeros and

			Acoculco geothermal fields, Mexico” (EGU2018- 7228)
		Damien Bonté (UU)	D. Bonté et al.: “Preliminary estimation of the thermal structure of the Acoculco-Los Humeros area, Mexico” (EGU2018-16270)
		Philippe Calcagno (BRGM)	P. Calcagno et al.: “3D preliminary geological models of Los Humeros and Acoculco (Mexico) - H2020 GEMex project” (EGU2018-12811)
		Eszter Békési	Békési, E. et al., “Active deformation of the eastern Trans-Mexican Volcanic Belt based on InSAR persistent scatterers” (EGU2018-15520)
		Giordano Montegrossi (CNR)	“Modeling of Los Humeros geothermal field: preliminary results”, EGU2018-17600
		Tania Toledo (GFZ)	Toledo, T., “Optimized Experimental Network Design for Earthquake Location Problems: applications to geothermal fields seismic networks”, EGU 2018-15056
		Juliane Kummerow (GFZ)	Kummerow, J., Raab, S., Schüssler, J., “Fluid-rock interactions at near- and supercritical conditions and their effect on physical properties of high-enthalpy hydrothermal systems” (EGU2018-7097)
		Paromita Deb (RWTH)	Deb et al., “Hydraulic-fracturing experiments on a laboratory scale for numerical codes verification” (EGU2018-16136)
		Francesco Parisio (UFZ)	Parisio F., Vinciguerra S., Kolditz O. and Nagel T., “The lithological control on the brittle-ductile transition in volcanic areas” (EGU2018-2429)
80th EAGE Conference	Copenhagen, Denmark, June 2018	Paromita Deb (RWTH)	Deb et al., Laboratory fracking experiments for verifying numerical simulation codes, 1354, Hydro-

			Thermal-Mechanical Modelling in Tight Formations
Breaking the Rules! Energy Transitions as Social Innovations, International conference hosted by the Leibniz Research Alliance on Energy Transitions	Berlin (Germany), June 14-15, 2018	Eleonora Annunziata (SSSA)	Annunziata, E., Contini, M., Diaz, F., Karytsas, S., Manzella, A., Padovan, D., Sciullo, A., "Public engagement strategy: a conceptual model for enhancing the development of geothermal energy"

Table 4: List of oral or poster presentations

2.2.5 Task 2.5 Events

The planning of events for the GEMex project is a continuous organisational task and closely linked to Task 2.1 *Strategic communication plan and communication campaign*. The first version of the events planning was achieved as Milestone 8 in project month 9 and is included as Annex 1 in Deliverable D2.1 *Strategic communication plan.* It specifies events in 4 categories: 1) project events, 2) scientific events, 3) information events for stakeholders, 4) workshops for consulting stakeholders.

Information events for stakeholders have been organized by the GEMex consortium or were attended by a representative of the consortium and are specified in Table 5.

Event	Location /Date	Who
GEMex Workshop on public acceptance	Morelia (Mexico), Feb 2017	(SSSA)
GEMex Workshop on Corrosion, Erosion and Scaling in Los Humeros	Los Humeros (Mexico), 7-10 March 2017	Ernst Huenges, Simona Regenspurg, Anna Jentsch (GFZ), Ingólfur Örn Þorbjörnsson, Gunnar Skúlason Kaldal (ISOR)
EU-MX dialogue on Energy (invited presentation on GEMex)	Mexico City (Mexico), 23 Jan 2018	Paromita Deb (RWTH)
European Science Diplomacy Week in Mexico (invited presentation on GEMex)	Mexico City (Mexico), 24 March 2018	Jan Diederik van Wees (TNO)
GEMex side-event at Descramble final conference and in conjunction with ETIP-DG	Pisa (Italy), 27 March 2018	K. Kieling, E. Huenges (GFZ), E. Trumpy (CNR), D. Liotta (UNIBA), D. Bonté (UU), J. D. van Wees (TNO), F. Poletto, B. Farina (OGS), C. Clauser (RWTH), V. Pinzuti (EGEC)

Table 5: List of information events for stakeholders

EGEC has organised the first workshop for consulting stakeholders: The GEMex Stakeholder Board held its first meeting on November 15th, 2017, in Brussels, Belgium. The fruitful discussion arose many interesting points, which touched, among other things, the lessons learned and next actions for market development.

Project meetings have been organised and conducted and are detailed in the report on Task 1.4 *Meetings.*

No **scientific events** have been organised in the reporting period, but the GEMex consortium has contributed presentations to several scientific meetings, as specified in the report on Task 2.4 *Promotion of project results*. A session on "International Research on Engineered and Superhot Geothermal Systems" has been proposed for the GRC (Oct 2018 in Reno, Nevada, USA) and will be chaired by members of the GEMex consortium.

Finally, during the first reporting period, GEMex WP2 staff participated to the Innovation and Networks Executive Agency (INEA) proposed activities. An overview of the GEMex project was given at the INEA meeting held in Bruxelles in June 2017. The INEA meeting was the occasion to start the cooperation with the Dissemination staffs of the running EU geothermal project funded within H2020 program. The cooperation, among the things, allowed to have a joint booth of the EU geothermal project on Deep Geothermal at GeoTherm expo & congress 2018.

Event	Location /Date	Who
INEA meeting (Coordinator's Day)	Brussels (Belgium), July 2017	Katrin Kieling (GFZ), Eugenio Trumpy (CNR), Valentina Pinzuti (EGEC)
Geotherm 2018; Joint booth with other deep geothermal H2020 projects	Offenburg (Germany), 1-2 Mar 2018	Katrin Kieling, Angela Spalek (GFZ), Eugenio Trumpy, Adele Manzella (CNR), Pierre Durst (BRGM)

Table 6: List of joint events with other H2020 projects

2.2.6 Deviations from the Description of Action

Task 2.4: RWTH has used 0.24 PM for Dissemination although this was not foreseen in the GA. Paromita Deb from RWTH took part in the EU-MX dialogue on Energy and gave an invited presentation on GEMex on behalf of the coordinator.

2.3 Work Package 3: Regional Resource Models

Lead: UU
Partners: BRGM, CNR, OGS, TUDA, UNIBA, UROMA3, UU
Duration: month 1-44
Status: started and ongoing

Objectives:

Work Package 3 is focusing on modelling the resources at regional scale both in Acoculco and Los Humeros. The models are geological (conceptual, numerical, and analogical), thermal, and hydrogeological. These models have for objective to characterize the geological and geothermal system in close collaboration with the geological and geophysical work respectively performed in WP4 of WP5. The understanding at regional scale on how the geological and geothermal systems have evolved and are structured will help the purpose of the other work packages.

Participant number	4	5	7	8	9	12	14	**Total**
Short name	UNIBA	UU	CNR	TUDA	BRGM	OGS	UROMA3	
PM foreseen in total GEMex	2	20	57	12	22	2	17	132
PM used	1	14.9	12.19	0	3.53	1	2	34.62

Table 7: Status quo of personal resources WP3

The work is benefiting from a strong working relationship between Europe and Mexico, both, with the academic partners and the industry partner CFE.

The progress of the activities (i.e., achievement of the foreseen Milestones and release of the due deliverables) and the resources used are in line with the timing and effort/cost proposed in the Grant Agreement (GA).

Minor deviations from the Description of Action are reported below in section 2.3.6.

Task 3.1 has the objective to gather each geo-scientific specialty around a common platform to build a shared understanding of the geological system in the form of a conceptual and 3D model (Deliverable 3.1). Main results are:

- 3 preliminary models: 2 for Los Humeros (local and regional) and a regional for Acoculco created as a collaboration between EU and Mexican partners. These models have been made available to the GEMex community through the VRE
- Published and unpublished data have been gathered for Acoculco and Los Humeros volcanic complexes and organized in a GIS environment.
- A report on the knowledge gathered regarding the conceptual model has been prepared and made available on the VRE

The progress of Task 3.1 is according to schedule. The MS10, MS11, and MS13 that were related to T3.1 have all been delivered on time.

Task 3.2 has the objective to create thermal and hydrogeological models to understand the geological, volcanological, and geothermal systems at regional scale for Los Humeros and Acoculco. The ultimate aims are to create a resource assessment of both sites.

The work on the thermal and hydrogeological modelling included first a collection of data (both for temperature and hydrogeology) specifically for the purpose of the modelling. Then, by using the geological structure and knowledge provided by Task 3.1 and WP4 a preliminary model has been built for the thermal structure in Los Humeros and Acoculco, and for the hydrogeology in Acoculco. Further knowledge will be provided by the update of the model in Task 3.1, and new knowledge mainly from Task 3.3, WP4 and WP5. Main results are:

For the thermal models

- Preliminary models both in Acoculco and Los Humeros with hypotheses that will be confirmed later on during GEMex (magmatic body parameters definition).

For the Hydrogeological model

- Information has been provided through collaboration with the Mexican team at CICESE currently working on quantitative hydrogeology (e.g. whatershed) and geochemical study. Theses information have led to the understanding of the boundary condition of the system allowing the modelling to progress with complete knowledge of the area.
- Additional information concerning the system were provided by CFE

The progress of Task 3.2 is according to schedule. The only milestone MS15 was slightly delayed (from M6 to M11) due to a discussion regarding the dissemination of data with CFE but this issue has been solved at GEMex level and the work in T3.2 is now back on track.

The **Task 3.3** has two main objectives addressing:

- the relationships between regional tectonics and volcanoes
- the surface deformation patterns related to the collapse of caldera and volcanic edifices.

Task 3.3 ‘Analogue modelling’ has started in October 2017 (M12):

- A field survey has been carried out in Los Humeros in November 2017, during which geological-structural data have been collected in cooperation with personnel of Task 4.2 and Mexican institutions. Post fieldwork, the collected data have been analyzed.
- A first series of analogue models has been carried out by CNR-IGG, starting in January 2018 and focused on the study of caldera collapse and the associated surface deformation.

The result of the T3.3 will be use by T3.1 and other partners that try to understand the evolution and structure of the volcanic edifices.

2.3.1 Task 3.1 Integrated regional models and characterisation of the geothermal and volcanic systems

The task T3.1 "Integrated regional models and characterization of the geothermal and volcanic systems" coordinated by the BRGM, gathers scientists from Europe and Mexico.

The Los Humeros and Acoculco sites are studied following three complementary 3D scales (Figure 4):

- Supra-regional, ~100x50-70x30-40 km
- Regional, 56x36x7b.s.l. km
- Local, 9.5x12.5x7b.s.l. km

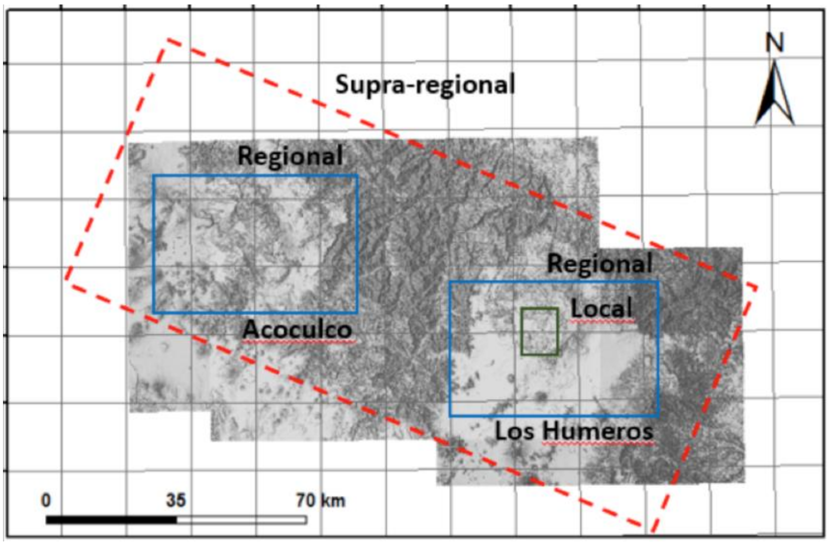

Figure 4: Boundaries of the local, regional and supra-regional models

The local scale is not described in the Description of Activity of the project, as T3.1 deals with regional integration. However, the scale of the exploitation in Los Humeros has been envisaged after the beginning of GEMex to fulfil the need of other partners, e.g. WP6 for simulation. In Acoculco, no local scale model has been built during the reporting period.

2.3.1.1 Management and internal dissemination

Several meetings, workshops, teleconferences have been organized during the reporting period to reach the milestones and deliverables of T3.1, and to communicate beyond the task framework within GEMex. These actions are listed in the following.

- Presentations and discussion took place at all project internal meetings
- Eight teleconference were held during the reporting period. (Minutes of these meetings are available on VRE)
- T3.1 Los Humeros tele-workshops (05-09/2017): From May to September 2017, **weekly** technical tele-workshops were organized by the LH 3D core team (EU+MX) to set up the Los Humeros 3D preliminary geological models
- T3.1 Acoculco tele-workshops (05-09/2017): From May to September 2017, **bimonthly** technical tele-workshops were organized by the AC 3D core team (EU+MX) to set up the Acoculco 3D preliminary geological models.

- WP4-T3.1 Los Humeros regional geological interpretation teleconference (13/12/2017): A teleconference was organized by WP4 to discuss the geological interpretation in LH at regional scale.
- Scientific Acoculco workshop (Potsdam, 26/01/2018): During the workshop and exceptional EB-meeting, the input of T3.1 was the base of further planning for WP5 (resistivity and gravity survey)

2.3.1.2 3D GeoModels

In agreement with the GEMex Description of Activity, the preliminary 3D geological models built in the scope of T3.1 are on the internal webpage since end-October 2017. Los Humeros regional, Los Humeros local, and Acoculco regional GeoModels are available on the internal project website.

These models delivered in October 2017 (MS11) consist in primary 3D interpretation of the main geological objects from existing data and knowledge. Consequently, geological interpretation of existing maps, boreholes, seismic profiles, or other media were adapted to integrate them properly in the models.

The preliminary models are coherent geometrical description of the main geological features to be taken into account for the geothermal objective of the project. These geological features were chosen and modelled in agreement with the help of the referent geologists and other relevant partners.

a) Methodology

- **Data compilation**: As requested during the Kick-off meeting of GEMex by the project coordination, a wish list was prepared in November 2016. It listed the main data and knowledge needed to start the building of the regional geological models. At the same time, a review of existing data and literature has been performed related to the construction of the GeoModels for Los Humeros and Acoculco. This phase ended in March 2017 with the milestone MS10 dedicated to the data compilation.
- **The implementation of the GeoModels** of Los Humeros and Acoculco started in May 2017. The construction of the models is conducted in a collaborative work gathering teams of European and Mexican colleagues. A loop was established through three main steps: (i) data & knowledge, (ii) modelling, (iii) validation. On a practical way, data & knowledge are proposed by the referent geologists. This information is then used to build the shapes of the models. The results are discussed and validated at the team level. Then, new or revised data & knowledge is input in a new loop, and so on, until the models are satisfying for the partners.

  The close connection between EU and MX is crucial in this process. Regular meetings are organized to allow the interaction as much as possible. These tele-workshops are organized on a regular basis, one every week or every second week, to discuss the vision of the geological objects in 3D, how they are modelled, to share documents, data, interpretation in cross-sections and boreholes, ideas, etc. In addition, data, comments, results (such as PDF3D) are exchanged among the team via e-mail.

- **Interaction with other WPs**: A close collaboration is in place with WP4 “Tectonic control on fluid flow” since the beginning of T3.1 to ensure a relevant geological interpretation from existing knowledge and new field acquisition. As scheduled, the interaction with WP5 “Detection of the deep structures” was less developed during the reporting period, mainly because of the field work that is still on going at the time of this report. However the preliminary models from T3.1 are already in use in WP5 (see d) below). The link with WP5 will be strengthened in the following period to better constrain the GeoModels. To initiate this process, a teleconference was held on 05/02/2018 to discuss a collaborative way of working between T3.1 and WP5.

Los Humeros integrated 3D models are conducted by BRGM. Acoculco modelling is driven by CNR, under the supervision of BRGM. All the GeoModels are built using the GeoModeller software.

b) Los Humeros

The geological map from Carrasco-Núñez et al. (2017b) and the two geological sections from Carrasco-Núñezet al. (2017a) and Norini et al. (2015) are the main references to set up the preliminary models. In addition, sixteen wells with a geological description have been provided by CFE. Considering the lack of information available on their geometry, the wells are considered as vertical. The Digital Elevation Model (DEM) is provided by INEGI (Instituto Nacional de Estadística Geogreafía e Informática).

The Los Humeros preliminary regional and local GeoModels are fully described in Evanno (2017) available on internal webpage. The update of the preliminary models will start at the end of the reporting period.

- Regional scale: The GeoModel at regional scale (56 km x 36 km x 12 km, i.e. down to 7 km b.s.l.) presents four geological groups (Figure 5: Los Humeros preliminary regional GeoModel): basement, pre-caldera rocks, rocks from the caldera, post-caldera rocks. The geological map (Carrasco-Núñez, 2017b) and sections (Carrasco-Núñezet al., 2017a; Norini et al., 2015) have been re-interpreted accordingly. The geological description of the wells made it possible to match all the information with the four groups selected for the modelling of the regional model.
  Eleven complementary cross sections were used to constrain the regional model. They were drawn according to the two references cross-sections cited above to ensure a coherent interpretation, for instance in terms of geological formations thickness.
- Local scale: The GeoModel at local scale (9.5 km x 12.5 km x 12 km, i.e. down to 7 km b.s.l.) presents nine units (Figure 6). The geological map (Carrasco-Núñez et al., 2017b) and geological cross sections (Carrasco-Núñezet al., 2017a; Norini et al., 2015) have been re-interpreted accordingly. It was not possible to match the wells’ description with the nine units for three of them among the sixteen wells available.
  One complementary cross section was used to constrain the local model.
  At the local scale, a geological and a geophysical CFE’s 3D models have been retrieved in the last months. Two reports have been made by Kristian Bär (TU Darmstadt) to describe these models. They will be used to update the preliminary T3.1 GeoModels with new information, e.g. more wells available.

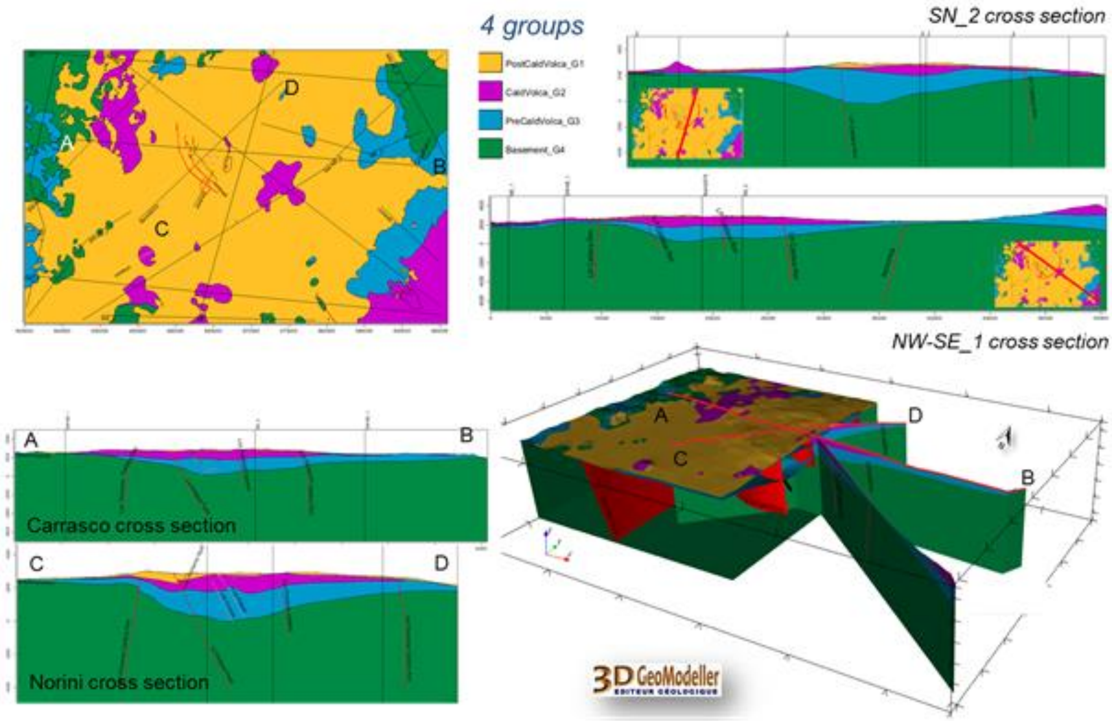

Figure 5: Los Humeros preliminary regional GeoModel

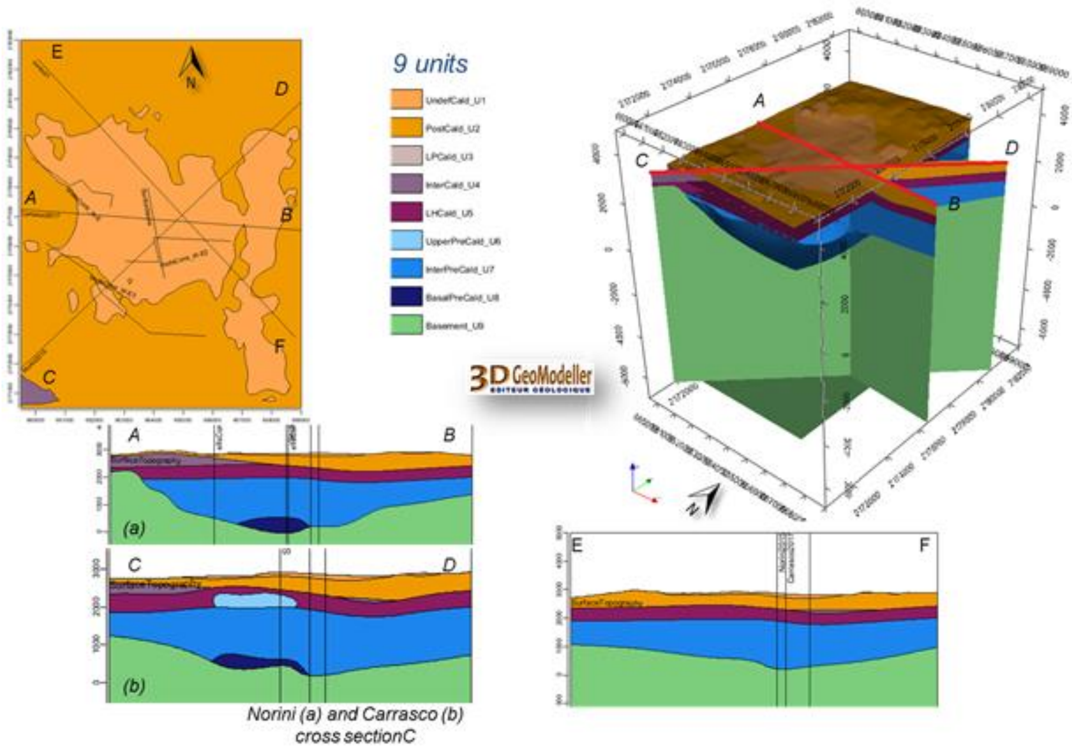

Figure 6: Los Humeros preliminary local GeoModel

c) Acoculco

The main reference for the Acoculco preliminary regional GeoModel is Avellan et al. (map and cross-section, in preparation). Relevant data from the two wells available on the site are also taken into account, as well as GEMex field work data. In addition, two geological cross-section have been interpreted to constrain the model at depth. The Digital Elevation Model (DEM) is provided by INEGI (Instituto Nacional de Estadística Geogreafía e Informática).

- The model covers 56 x 37 km, down to 7 km b.s.l. Five groups of rocks are modelled. The basement, that is the foreseen geothermal target for Acoculco, is split in four units while all the volcanic rocks are gathered in a single unit (Fig. 4).

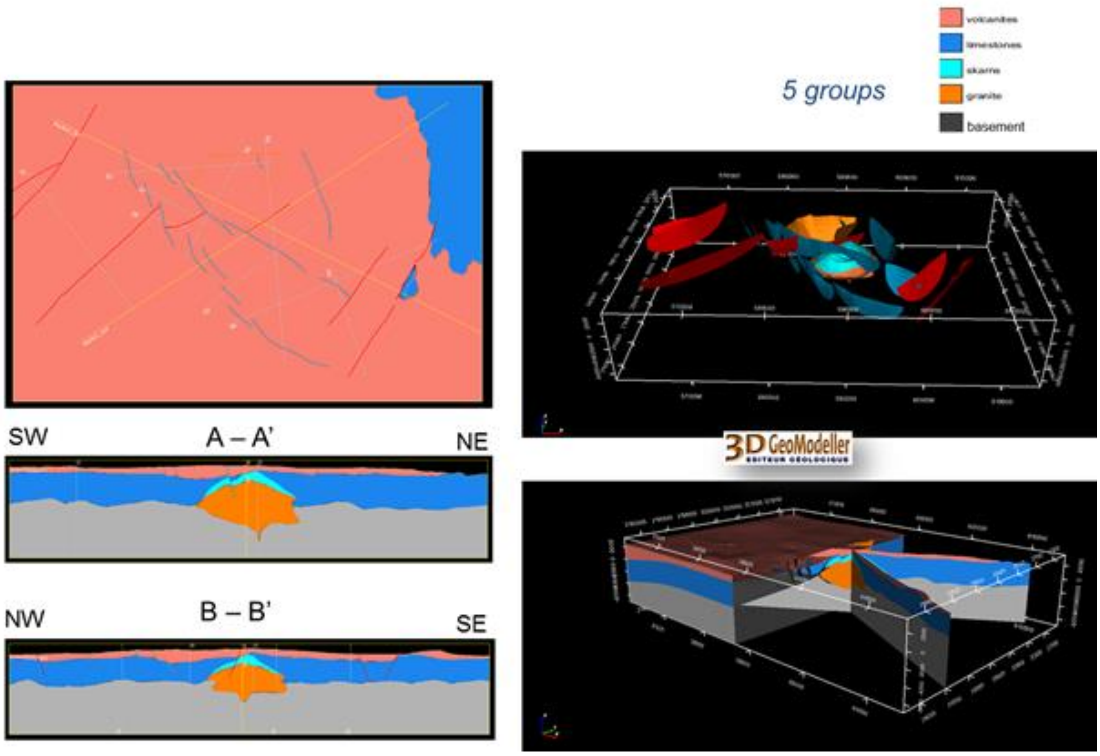

Figure 7: Acoculco preliminary regional GeoModel

d) Use beyond T3.1

The preliminary T3.1 GeoModels are used by other GEMex partners since they have been released in October 2017. This activity is described in Table 8.

Task	Preliminary GeoModel in use	Purpose	Partner
T3.2	Los Humeros local and regional	Hydrogeological simulation	BRGM
T3.2	Acoculco regional	Thermal modelling	CNR
T4.2	Los Humeros local and regional Acoculco regional	Geological interpretation	Uni Bari CNR
T5.1	Acoculco regional	Modelling inversion of geophysical EM data from CFE and literature	CNR
T5.2	Los Humeros local and regional	Seismic data analysis	OGS
T5.4	Los Humeros local and regional	Elastic modelling	OGS
T6.2	Los Humeros local	Understanding the relationship between the geological surfaces and the feed zones obtained from analysing the production data and heating up profiles of wells.	CNR RWTH
T6.4	Los Humeros local and regional	Heat transport and fluid flow simulation	RWTH

Table 8: List of tasks using preliminary GeoModels

2.3.1.3 Conceptual models

The information used to build the volcanological conceptual model is organized to compile deliverable D3.2 and feed the activities for D3.1. A review of existing data and literature has been performed related to the construction of the volcanological conceptual models for Los Humeros and Acoculco. This phase ended in March 2017 with the milestone MS10 dedicated to the data compilation. A draft version of the "Regional Structural and Tectonic Synthesis of the Acoculco and Los Humeros Geothermal fields" was delivered in June 2017 to the project consortium.

At the supra-regional scale, the conceptual model intends to present the geothermal system down to the Moho including the geothermal gradient.

The same extension for the regional scale has been chosen for both conceptual and 3D geological models. It is proposed that the conceptual model uses the geological framework, and that the geological interpretation benefits from the conceptual model, especially in the areas with low data availability.

- We started to model the plumbing system to define the geometrical extent, location, longevity, temperature of the heat source. The basement rocks and the volcanic pile are reconstructed within their stratigraphic, alteration and structural settings also in terms of permeability and role within the geothermal system.

- Data have been gathered from all possible sources accessible so far, including the new data that are becoming progressively available from the GEMEX project.
- Data collected are progressively archived and catalogued. All relevant data that can be georeferenced are geopositioned in formats that can then be shared with the other participants (as rasters or as .shp of polygons, lines and points along with their associated information and metadata). Data are currently organised to feed the supra-regional conceptual model aimed at defining the boundary conditions for the regional conceptual model, focussed on the definition of the magmatic source and its associated volcanic system.
- Published and unpublished data have been gathered for Acoculco and Los Humeros volcanic complexes, eastern Trans-Mexican Volcanic Belt. This synthesis is meant to be used in combination with the ArcGIS geodatabase available at Roma Tre that contains all the relevant information. Although the dataset extends far beyond the geographical location of the two study areas (Los Humeros and Acoculco), the spatial distribution of the gathered data is described for an area of about 250 km x 250 km. Gathered data cover:
    - Mechanic Stratigraphy at crustal scale
    - Thermal structure of the crust
    - Structure of the upper crust
    - Local Geology
- Two fieldwork campaigns have been conducted to update both the Los Humeros local and regional conceptual models with petrological and volcanological inputs. The first fieldwork took place in May 2017. The second one in November 2017 was specifically dedicated to petrological study where the Los Humeros magmatic rock sampling followed the new geological map from Carrasco-Núñez et al. (2017b) in Terra Digitalis and the new chronologic framework published in Carrasco-Núñez et al (2018). Results will also be provided to Task 6.1 to better understand how rock type, geochemical composition, texture and degree of alteration influences the petrophysical and mechanical properties.

2.3.1.4 Achievements

Milestone MS10 “Identification and gathering of all known geological and geophysical information regarding the geothermal systems of Los Humeros and Acoculco” achieved. A list of data is available on the internal website.

Milestone MS13 “Knowledge concerning the volcanological structure and evolution at the regional scale” was achieved. A short report is available on the internal website.

Milestone MS11 “Integration of all the initially gathered information and construction of an integrated 3D model” consists in the preliminary GeoModels of Los Humeros regional and local, and Acoculco regional. Each one comes with:

- Metadata sheet for more information
- GeoModeller files
- PDF3D file
- TSurf files

2.3.2 Task 3.2 Integrated geothermal models and resource assessment

The task T3.2 "Integrated geothermal models and resource assessment" coordinated by Utrecht University, regroup scientist from Europe and Mexico. The task covers the whole length of the GEMex project but the main deliverables are due at M30. For this reporting period, the regional scale has been considered for both Los Humeros and Acoculco sites (Figure 4).

2.3.2.1 Management and internal dissemination

In addition to the numerous bilateral interactions between collaborators working on similar aspect in Europe and Mexico, discussions have occurred at all the GEMex meetings during the reporting period to reach the milestones and deliverables of T3.2.

2.3.2.2 Resource assessment: thermal modelling

In agreement with the GEMex Description of Action, the task 3.2 has a dedicated component to extend the knowledge of the subsurface temperature. Los Humeros is a complex system that is convectively transporting heat at reservoir level (core of WP6), but little is known regarding the thermal structure beyond this central part of the system where the exploitation of the geothermal system is occurring. The regional thermal modelling is primarily interested in understanding and characterising the regional thermal variations that show the impact of the large scale and regional aspects.

The work has mostly been perform by UU and CNR in collaboration with TUDa and UNIBA. An important aspect to mention here is the fruitful collaboration that has been put into place with the academics GEMex Mexico counterparts and CFE.

The first step was to collect the required information. The preliminary model is a first attempt to gather and regroup all known information such as the structure of the volcano-sedimentary pile (from Task 3.1), the pre-GEMex knowledge at regional scale that has been comprehensively put together by Uni Roma 3 in the MS13, compositional information from T6.1 and field information from WP4.

a) Thermal structure of Los Humeros: preliminary results (lead: D. Bonté – Utrecht University)

Collection and analysis of the temperature measurements.

The first activity concerns the retrieving and analysis of the temperature measurements in Los Humeros (and Acoculco) which lead to milestone MS15 *Gathering of existing temperature information completed and knowledge in Acoculco and Los Humeros* that was due at M6 but due to a slow start of the collaboration had to be postponed by a few month. The very positive point is that this initial temperature request has contributed to open a trustful channel of communication between GEMex and CFE. Overall, the temperature information, together with multiple other information (e.g. pressure, well path), has been received from CFE in two batches of first 16 wells and then 36 wells for a total of 52 wells for Los Humeros and 2 wells in Acoculco (the only 2 that have been drilled). Those consist of continuous temperature logs in each well at deferent thermal recovery time allowing interpretation from a thermal point of view.

In Los Humeros, a first aspect to be considered is the temperature logs time series. The temperature values have not been measured after enough resting period and the temperatures remain perturbed. Consequently, temperature measurements at the bottom of the well have been collected and corrected using the ICS method described in Goutorbe et al. (2007).

Preliminary modelling results

The methodology used the B3T modelling tool described thoroughly in Limberger et al., 2017. The result is a 3D thermal block that has the extension of the regional model of Los Humeros developed in T3.1 and show variation according to the temperature. The next step will be to systematically integrate newly created knowledge concerning the deeper and regional part of the model.

b) Setting of the regional thermal model in the Acoculco area (lead : G. Gola - CNR)

The main activities related to the processing of the available temperature data measured in the EAC-1 and EAC-2 wells and the setting of the regional numerical model to study the thermal structure of the Acoculco geothermal field.

- **Extrapolation of static temperatures**: The time-temperature series acquired during the thermal recovery of the boreholes after drilling (up to 24 hours) permitted to extrapolate the static temperatures by the application of the well-known Horner Plot method. In both the wells, the resulting static profiles show common features: i) a mainly conductive heat transport dominates the underground thermal structure and ii) starting from a roughly linear geothermal gradient in the range 106 – 117 °C/km in the first 1.7 – 1.8 km, the deepest logged intervals display a rapid increase of the thermal gradient up to 275 – 355 °C/km.
- **Regional thermal modelling**: The regional thermal model was set up with the aim to test the working hypothesis about the existence of a recent and relatively shallow magmatic intrusion that induced in the overlaying rocks a transient thermal signal capable to justify the observed temperatures. The geological model performed in the WP 3.1 has been imported in the numerical domain and each geological layer has been characterized by a set of petrophysical properties controlling the time-dependent conductive heat transport. The comparison between the numerical results and the measured thermal profiles constrained the actual thermal structure to the warming or cooling early-stage evolution. We would stress that the current regional model represent a preliminary scenario. More activities are planned, principally the integration of other geothermal exploration proxies (e.g. geophysical, geochronological and petrological data) in order to better constrain the deep structures and the thermal evolution of the region. As the Acoculco geothermal field has not been yet explored in detail, large uncertainties may exist due to the lack of data. In the next steps, a sensitivity study will be performed by a Monte Carlo approach.

2.3.2.3 Regional hydrogeological model of Los Humeros area

One of the objectives of the work performed in task 3.2 by BRGM is to use the Los Humeros 3D geological model built in Task 3.1 to integrate all the available information into a conceptual regional hydrogeological model in collaboration with European and Mexican partners. This model will provide a quantitative tool to have a regional understanding of the fluids in the systems, their origins, interactions, and paths as well as testing hypothesis or assess uncertainties.

a) Status of current work

Main activities

- Collection of data concerning the regional hydrogeology of Los Humeros (ongoing, master thesis of Christober Barge (Feb. – July 2018), in cooperation with Mexican partner)
- Mexican partners: quantitative hydrogeological and geochemical study, including acquisition of field data, of the regional watersheds
- All available data concerning hydrogeology of the area (and temperature distributions) is gathered in the same GIS system that has been used to build the geological model.
- A lot of effort is currently put in setting an operational workflow to go back and forth between geological model (GeoModeller) and hydrothermal model (ComPASS) including :
  - meshing of the geological model (done with the CGAL library),
  - comparison of model results with available data

  Then, the calibration of boundary conditions should enable the reproduction of a first and rough regional distribution of hydraulic heads and temperature distribution. This preliminary model will be used to explore the effect of regional structures on fluid flows.
- A skype meeting was held on March the 1st to synchronize the work between European WPs 3, 4 and 6 and Mexican partners.

Preliminary results

The watersheds of the area are quite extensive. They are more or less overlapping with the geological model built in task 3.1. An important point is that one of the watersheds is a closed watershed which has implication on the type of boundary conditions at the regional level and the way to integrate evaporation from the system. Most of the eastern flank of the area is considered to be a recharge area, what seems to be confirmed by isotopes. The most important pathways for fluids seem to be 1) the carbonate aquifer outcropping all around the watershed and 2) the main fault zones. There is very small precipitation in the caldera area whereas it can reach 1500mm in some area of the watershed. Pico de Orizaba (the highest peak in Mexico) is at the southern part of the watersheds.

2.3.2.4 Achievements

Milestone MS15 “Gathering of existing temperature information completed and knowledge in Acoculco and Los Humeros established” has been achieved. Data is available to the project consortium in the internal website.

2.3.3 Task 3.3 Analogue modelling

Summary of Activity

The activity of Task 3.3 ‘Analogue modelling’ has started in October 2017 (M12). The main aims of Task 3.3 regard the interplay between tectonics and magmatic processes in shaping volcanic edifices, in order to understand specific volcano-tectonic issues relevant for the geothermal exploration of the study area. Task 3.3 aims to address two main research questions: (1) interactions between regional tectonics and volcanoes, and (2) collapse of caldera and volcanic edifices, and the associated surface deformation. These questions will be answered by using analogue modelling, which is an experimental technique that allows to study geological processes in the laboratory through the analysis of scaled physical models, built and deformed at reduced geometrical and temporal scales. More specifically, the above-mentioned research themes will be tackled in deliverables D3.5 (Report on the analogue modelling of the interactions between regional tectonics and volcanoes) and D3.6 (Report on the analogue modelling of the collapse of caldera and volcanic edifices and the associated surface deformation), respectively.

2.3.3.1 Activity

Literature review: The activity has initiated with the gathering and review of scientific literature regarding the geology of the study area, as well as previous analogue modelling studies related to the scientific issues addressed by Task 3.3. In particular, the existing literature on the surface and subsurface data has been reviewed (including all the available CFE wells) to develop a conceptual model of the plumbing system beneath the Los Potreros caldera (LPC), which is the most active part of the Los Humeros volcanic complex (LHVC), and currently is the main target for geothermal exploration and production.

Workshop on Task 3.3: The task kick-off meeting was held in Florence in April 2017 to define the strategy of the modelling work to be performed by the different partners involved in Task 3.3.

Field survey: A field survey has been carried out at the LHVC in November 2017, during which geological-structural data have been collected in cooperation with personnel of Task 4.2 and Mexican institutions. We have measured structural data at 23 main sites, collecting fault-slip data, orientation of magmatic dikes, joints, and subordinately axes and axial planes of folds (see Figure 8). The measurement sites occur within the LHVC, as well as in the surrounding pre-volcanic basement (mostly Mesozoic carbonates). Fault and fracture data have been dominantly collected within the LPC, which lies within a broader and older caldera, referred to as Los Humeros caldera (LHC) (see Figure 8).

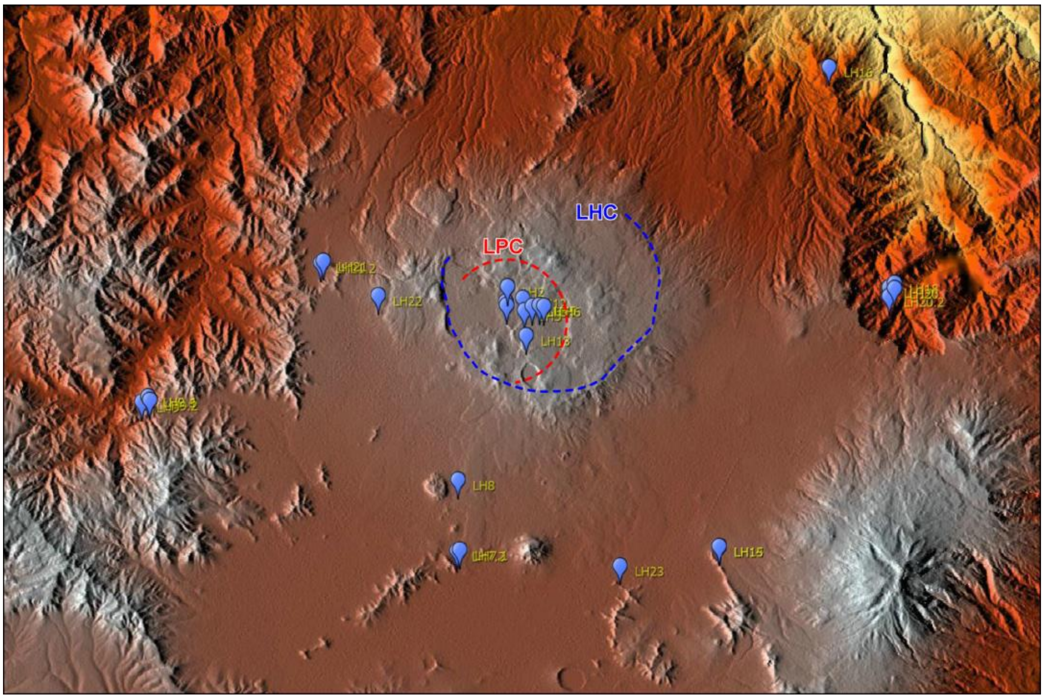

Figure 8: Measurement sites for structural data

Data analysis: After the field work, the collected structural data have been analysed and elaborated; in particular, stress inversion methods (right dihedron angle and *P* and *T* axes) have been applied to fault populations to obtain the principal stress axes. The location of the sites of measurement and the raw structural data have been uploaded on the internal VRE platform.

Analogue modelling: A first series of analogue models has been carried out by CNR-IGG. This series has started in January 2018, and focused on the study of caldera collapse and the associated surface deformation. Literature data report that the LPC is characterized by a resurgent block, and thus our experimental set-up has included both caldera collapse and subsequent intra-caldera resurgence. The model set up consists of a brittle overburden overlying a low-viscosity Newtonian fluid simulating a circular magma chamber. During the first phase the analogue magma is evacuated through a tube below the model, after that (phase 2) the analogue magma is intruded to simulate intra-caldera resurgence.

Definition of conceptual model for upcoming analogue models: In addition, the review of literature data, together with field observations, suggested that granitic intrusions (found in wells H5-H11-H19-H20-H25-H26-H37) are trapped in the soft caldera group ignimbrites (layers with low cohesion and rigidity), between the more rigid layers of the pre and post caldera succession (Teziutlan andesite and basaltic andesite). The ascent of such highly viscous intrusions may induce the resurgence and deformation of the eastern part of the LPC floor. These data have allowed the definition of a conceptual model that will be used to define the boundary conditions to be imposed to a series of analogue models that will be carried out by Roma 3 University.

2.3.3.2 Summary of results

Field work: Evidence for recent faulting affecting the volcanic edifice has been nearly exclusively found within the LPC, where faults often deform ca. 6 ka old pumices, and define a sub-radial pattern. The Maztaloya/Los Humeros fault (MLHF) is the main structure of this system, and extends across the whole LPC in a roughly NNW-SSE direction. Kinematic indicators reveal dominant normal faulting on the MLHF and other main faults. Reverse faulting has also been occasionally observed on some minor fault segments within the LPC. Inversion of fault-slip data collected on the MLHF and other secondary normal faults splaying from this structure yield extension directions varying approximately between ENE and WSW. Structures in the pre-volcanic substratum mostly consist of ca. NW-SE trending folds and thrusts formed during the Laramide orogenesis. Cross joints sub-orthogonal to the fold axes often represent the dominant set. Magmatic dikes frequently exploit ca. NE-trending pre-existing discontinuities in the pre-volcanic substratum. At a larger scale, some volcanic centres are aligned along NNE to NE directions, suggesting a control of similarly oriented structures.

Analogue modelling: The first models carried out by CNR-IGG were dedicated to test the model set up and reproducibility of results. Then, we have started the experimental work that has initially addressed the role of the overburden thickness (above the analogue magma chamber) on caldera collapse. The main preliminary modelling results are the following: (1) caldera collapse is invariably accommodated by both normal faults and reverse faults. Reverse faults are the first structures to develop, while normal faults develop at late stages and form the most external caldera ring. (2) Subsidence of asymmetric caldera is accommodated by trapdoor collapse characterized by the tilting of a roof block. (3) Caldera ring faults often show an along-depth dip variation. (4) Magma resurgence is often accompanied by the reactivation of pre-existing caldera faults. Future modelling work will also focus on the interaction between volcano edifices and the pre-existing regional tectonic structures defined from tasks 4.1 and 4.2.

2.3.4 Publications

Evanno, G., 2017. 3D preliminary geological modelling of the Los Humeros geothermal area (Mexico). Master Thesis, ENAG/MFE-088-GB-2017, 123 pp.

2.3.5 Dissemination activities (talks, posters, workshops)

Bonté, D., Limberger, J., Békési, E., Beekman, F., van Wees, J.-D., 2018 (accepted).Preliminary estimation of the thermal structure of the Acoculco-Los Humeros area, Mexico. European Geosciences Union General Assembly, EGU2018-16270, Vienna, Austria.

Bonté, D., et al., Regional resources models: Integrated regional models, GEMex information event, Pisa (Italy), 27 Mar 2018

Calcagno, P., Evanno, G., Trumpy, E., Gutiérrez-Negrín, L. C., Macías Vásquez, J. L., Carrasco, G., Liotta, D., and the GEMex T3.1 team, 2018 (accepted).3D preliminary geological models of Los Humeros and Acoculco (Mexico) - H2020 GEMex project. European Geosciences Union General Assembly, EGU2018-12811, Vienna, Austria.

Calcagno, P., et al., State of the art of the Gemex WP 3: Integrated regional models, GEMex Stakeholder Board meeting (Brussels, Belgium, 15/11/2017)

Jolie, E., et al., GEMex - A Mexican-European Research Cooperation on Development of Superhot and Engineered Geothermal Systems. Proceedings, 43rd Workshop on Geothermal Reservoir Engineering, Stanford University, Stanford (CA, USA), 2018

Montegrossi, G., Deb, P., Clauser, C., Diez, D., Ramirez Montes, M. A, 2018 (accepted). Modeling of Los Humeros geothermal field: preliminary results.European Geosciences Union General Assembly, EGU2018-17600, Vienna, Austria.

2.3.6 Deviations from the Description of Action

Tasks 3.3: The analogue modelling laboratory of CNR-IDPA has rescheduled its activity with the aim of a better integration among the three analogue modelling laboratories involved in the Task 3.3 (CNR-IGG, CNR-IDPA and UROMATRE) and an efficient use of their instrumental resources. For this reason, the laser scanner mentioned in the GA will not be acquired, and the budget will be used for other equipment and eligible costs. Nonetheless, the duties, deliverables and schedule of the laboratory will not be affected by this deviation, as the analysis will be conducted with alternative techniques (digital photogrammetry) in collaboration with the other two laboratories.

2.4 Work Package 4: Tectonic control on fluid flow

Lead: UNIBA
Partners: BGS-NERC, BRGM, CIPR, CNR, GFZ, IFE, ISOR, PIG, UNIBA, UROMA3
Duration: month 1-30
Status: started and ongoing

Objectives:

Work Package 4 is aiming at an understanding of the relationships among geological structures and physical and chemical properties of high temperature geothermal resources in volcanic systems. The objectives can be summarized as follows:

1. Study of the relationships between brittle geological structures and fluid flow in fossil, analogue, geothermal systems as a key for understanding the deep structures in Los Humeros.
2. Study of the chemical and physical characteristics in the paleo-fluids in order to define their chemical and physical characteristics.
3. Study of the relationships between brittle geological structures and super hot fluid flow in Los Humeros.
4. Study of the relationships between brittle geological structures and fluid flow in Acoculco, for contributing to the understanding of the geological conditions at which EGS can be performed.
5. Physical and chemical characteristics of the geothermal and cold fluids in Acoculco and Los Humeros.

These five objectives include: indications on the stress field, distribution of fractures and geological evolution of the three study areas and geochronological analyses in order to constrain their geological evolution in terms of geothermal issues.

Participant number	1	2	4	7	9	10	13	14	18	21	**Total**
Short name	GFZ	ISOR	UNIBA	CNR	BRGM	IFE	CIPR	UROMA3	NERC	PIG	
PM foreseen in total GEMex	36	24	69	70	10	12	18	48	8.5	36	331.5
PM used	20.8	10.4	41	40.3	3.2	8	17.5	18	7.4	11.9	178.4

Table 9: Status quo of personal resources WP4

The WP4 activities are carried out together with the Mexican colleagues in all its scientific aspects.

The progress of the activities (i.e., achievement of the foreseen Milestones and release of the due deliverables) and the resources used are in line with the timing and effort/cost proposed in the Grant Agreement (GA).

Minor deviations from the Description of Action are reported below in section 2.4.7.

WP4 is dedicated to:

1. the study of the exhumed geothermal system (Las Minas area) in order to shed light on the structures affecting and controlling the fluid paths at depth in Los Humeros;
2. the study of Los Humeros geothermal system with the aim to better understand the structures controlling the superhot fluid paths;
3. the study of Acoculco area, in order to contribute (by fieldwork) to define the geological conditions at which EGS will be simulated;
4. the definition of the physical and chemical characteristics of the cold and hydrothermal fluid in Acoculco and Los Humeros.

Regarding the first point, a new geological map of the **Las Minas** area is going to be concluded, based on the revision of the stratigraphic and petrologic settings as reconstructed from fieldwork and rock-samples analyses. Paleo-fluids having determined the hydrothermal mineralization are studied by fluid inclusion and isotopic analyses. Preliminary results indicate that part of the paleo-fluids were trapped in a magmatic-skarn hydrothermal system similar to that likely present below the Los Humeros exploited geothermal reservoir. Thus, the study of the Las Minas fossil exhumed system will give information on the possible exploitation of a deep super-hot reservoir at Los Humeros.

The fieldwork study of **Los Humeros** area is based on the integration between structural and kinematic data with geomorphological analysis of available digital terrain models and satellite images, and with stratigraphic, volcanological and petrological data from outcrops and rock-samples (sampling was partly conducted together with WP6). The results indicate that the caldera area is characterized by a sufficient permeability as a consequence of the interplay between pre-existing regional structures (SW-NE and NW-SE oriented) and structures developed during the caldera collapse and resurgence. It is also inferred that the regional structures acted as conduits to drive the meteoric recharge of the geothermal systems. The stratigraphic and petrological study carried out in the Los Humeros area permitted to shed light on the most recent volcanic events, believed to be strictly linked to the present geothermal system. New Ar-Ar and U/Pb datings show a much younger age for the peak caldera volcanism and the extent of the build-up phase (see Carrasco-Núñez et al., 2018).

Acoculco studies highlighted two main active geological trending structures, NW-SE and SW-NE oriented, respectively. The study of their kinematics permitted to infer the present stress field that is consistent with the extensional tectonics affecting the area. The whole area where the CFE boreholes (that are supposed to be used for the EGS system) were drilled, has been studied in detail. The results indicate that the boreholes are presumably located in footwall of an active SW-NE oriented normal fault, NW dipping. If this will be confirmed by indirect studies, their distance from the permeable zone is estimated to be in about 200 m, thus resulting as an excellent site for the EGS simulation studies, though the potential induced reactivation of the fault has to be assessed as part of WP7 to avoid unwanted induced seismicity at possibly significant magnitudes.

As it regards the **geochemical study of cold and geothermal fluids** carried out in Los Humeros, the isotopic characterization of collected samples from cold springs allows to obtain information regarding the altitude vs dD‰ (d18O‰) local relation. These findings represent a novelty for LHGS and suggest that different regional “feeding zones” seem to be present.

Finally, regarding high temperature tracers to be used in the geothermal wells for monitoring the geothermal flux, IFE performed several tests: Two tracers were stable at 250°, but recoveries were low with Basalt in the vials. A third tracer had near 100% recovery at 350°C (both without and with Basalt in the vials). Moreover, this tracer was fully recovered in a flow experiment at 250°C. A patent is filed.

2.4.1 Task 4.1 Understanding from exhumed systems

In this task, the region around Las Minas is investigated. This area is located close to the Los Humeros geothermal field, and it is considered as the fossil, exhumed analogue of the present geothermal field. It is in fact characterised by both a similar stratigraphic volcanic succession and carbonate substratum. In Las Minas, the heat source of the paleo-geothermal system, now represented by multiple Neogene magmatic intrusions, is broadly exposed. The hydrothermal circulation is testified by Cu-Au-Fe ore deposits, almost represented by skarn masses and minor hydrothermal quartz-veins.

2.4.1.1 Main activities

In the first reporting period, the team of Task 4.1 has performed the following main activities:

- **The revision of the existing bibliography and geological maps** was carried out at the beginning of the project (4 months). The results of this study were used to prepare the fieldwork
- **Fieldwork**, consisting of 6 periods (approximately 10 days each, partly joined with other WPs)
    - rock sampling (rock-samples for petrographic and fluid inclusions analyses)
    - collection of structural and kinematic data on fault surfaces
    - revision of the stratigraphic column exposed in the deep incision of Las Minas
    - scan-lines of key-outcrops (SWIR hyperspectral outcrop scans)
    - drone photography
- study of **rock-samples and thin sections**
- **analysis of fluid inclusions**
- **Sr-Nd-Pb isotope determination**
- **geochronological studies (U/Pb and Ar/Ar):** analysis of 7 samples (4 from Las Minas, 3 from San Miguel Tenango) finished, analysis of 36 samples (33 from Las Minas, 4 from San Miguel Tenango) is ongoing.
- **Presentation** of activities and results at internal project meetings, at event for stakeholders and at scientific events

Out of those, some activities, always in cooperation with our Mexican colleagues, were finalized:

- to review the already mapped geological structures;
- to revise the stratigraphic setting;
- to collect structural and kinematic data, to reconstruct the local stress field at the time of the geothermal circulation;

- to define the geochemical characteristics of the paleo-fluids;
- to date rock-samples, in order to better constrain the geological evolution of the analogue.

2.4.1.2 **Main results**

The main results indicate that the existing map needs to be updated with new structures affecting both the substratum and the volcanic succession, partly. These structures are NW-SE and, dominantly, SW-NE trending. Along these trends the permeability was effective, as indicated by the distribution of the magmatic dykes and some hydrothermal mineralizations. The main shear zone is however SW-NE oriented and it seems to have influenced the location of skarn deposits. The stratigraphic column exposed in the deep incision of Las Minas was revised and updated by the discovery of a basaltic lava upon the limestone and of lacustrine sediments deposited before the evolution of the Los Humeros caldera. The collection of structural and kinematic data on fault surfaces indicate that the two above mentioned fault systems were characterized by different kinematics during fluid flow: a normal kinematics dominantly characterizes the SW-NE trending faults, whereas a right lateral strike-slip to right lateral oblique slip kinematics typifies the NW-SE fault system. Furthermore, the distribution and textural features of fractures at the outcrop scale are under study by scan lines including orientation, frequency and size data, together with mechanical properties of the fractured blocks. This ground-level data is extrapolated to the fracture geometry captured in 3D models built from drone photography. These datasets are already collected in key-outcrops, in cases including SWIR hyperspectral outcrop scans (3D models archived at Uni Research CIPR).

The study of rock-samples and thin sections allowed us to better characterize the magmatic bodies, the skarn, in terms of their mineralogy and petrological evolution, their mineralogy and to typify the hydrothermal association. The composition of the main intrusive body is quarzodioritic to granodioritic and the level of emplacement, calculated using the thermobarometry methods, is 4.7 $\pm$ 0.6 km. This body is intruded by multiple injections of magma related to different events. The first is mainly characterized by granodioritic to granitic dykes, while the second is more mafic. The mineralogy of the skarn linked to the magmatic intrusion, is dominated by garnet and clinopyroxene associated to quartz and plagioclase. Skarn bodies have also been affected by hydrothermal circulation testified by some hydrous minerals (epidote, chlorite) and ore deposits mainly composed by sulphides (pyrite, chalcopyrite) and locally by Fe-oxide (magnetite).

Fluid inclusions have been analyzed in quartz associated to skarn and in late hydrothermal quartz. Four main fluid inclusion types have been distinguished on the basis of microthermometric and Raman data and their optical characteristics at room temperature: 1) L-type, two-phase (liquid + vapor) liquid-rich, aqueous inclusions; 2) V-type, two-phase (liquid + vapor) vapor-rich, inclusions, containing low-density CO_2 in the vapor phase; 3) V_{CO2}-type: three- or two-phase (liquid H_2O + vapor CO_2 ± H_2S ± liquid CO_2) gas-rich inclusions; 4) LH-type: multiphase (liquid + vapor + halite ± hematite ± magnetite ± undetected solids) aqueous, liquid-rich inclusions. Hypersaline LH-type inclusions record the circulation of high-temperature magmatic derived fluid, while, moderate to low-salinity L-type inclusions could result from the mixing of hypersaline magmatic fluids with meteoric waters. V-type inclusions likely testify boiling processes in the system, whereas V_{CO2} inclusions possibly trapped aqueous-carbonic fluids issued during metasomatic processes on carbonates, which formed Ca-bearing silicates of skarn. Thus, LH-type and V_{CO2}-type inclusions record a magmatic-skarn hydrothermal system similar to that possibly occurring within the basement at Los Humeros, below the present-day exploited reservoir. On the other hand, the fluids trapped in L-type inclusions show some features which are more similar to those of the fluids stored in geothermal reservoirs.

The samples, processed for Sr-Nd-Pb isotope determination, have been carefully selected among the collected rocks from Las Minas exhumed complex. They consist of igneous rocks and limestone subjected to thermometamorphism of the Mesozoic basement together with samples of hydrothermal origin found as veins (mainly calcite) or pervasive skarn secondary minerals (mica, garnet and magnetite) within the host rock. Igneous rocks are both intrusive or subvolcanic sills.

Finally, geochronological studies (U/Pb and Ar/Ar) are on course to date rock samples, in order to better define the geologic evolution, and on hydrothermal minerals collected along shear planes, with the aim to date the fluid flow during fault activity. Regarding zircon U-Pb isotope geochronology (using SHRIMP IIe facilities) executed by PGI-NRI team, studies involving 4 samples from Las Minas area were carried out till now. The samples include plutonic rocks from basement units, preliminary confirming their Miocene/Pliocene age and one volcanoclastite of Pleistocene age, in which also older, Carboniferous and Jurassic zircons were identified. Additional 33 samples collected in January 2018 for U/Pb isotope and magneto-stratigraphic studies are being analysed.

Another example of exhumed system, studied for better understanding of the regional setting around Acoculco caldera is represented by the San Miguel Tenango geological units. For purpose of the U/Pb isotope zircon datings three samples of andesites from Diatrema Zacatlan Puebla, which intrude Jurassic and Cretaceous limestones, were analysed so far. Preliminary results point to early Pliocene age of these volcanics. Another 4 samples (basalt, granites, ignimbrite) of the pre-caldera successions are currently investigated.

2.4.2 Relationships between brittle structures, and fluid flow in active systems (Los Humeros and Acoculco)

2.4.2.1 Los Humeros

The review of bibliography and analysis of existing geological maps engaged the WP4 group in the first period (about 3-4 months) of activities. In the same period, **an in depth geomorphological analysis of digital terrain models and satellite images** has been conducted. These preliminary studies, in cooperation with our Mexican colleagues, permitted us to **plan the forthcoming fieldwork**.

Several fieldworks (4 periods of about 20 days each) and **laboratory analyses on rock-samples and thin sections** have been carried out in this study area, always in cooperation with colleagues from the Mexican consortium and from the CFE company. The lab-studies are finalized **to petrographic analyses** to be correlated with sampling campaigns of WP6 and SWIR hyper-spectral scanning of selected well cores with the aims to better explain the processes governing the reservoir properties.

These activities are dedicated to:

- collect kinematic and structural data from the caldera area and surroundings;

- define the geometric setting of the geological structures and the stress field present during their development;
- collect rock-samples, in order to better define their mineralogical composition and evolution, and to get information on the magma source and its depth;
- the analysis of the stratigraphic succession and physical volcanology from field and borehole observations, in order to better constrain the geological evolution of the caldera complex;
- collect rock-samples for Ar/Ar datings, archaeomagnetic and isotopic studies;
- structural analysis of the sedimentary rock-substratum, cropping out in the surroundings of the study area.
  - The collection of kinematic and structural data within the caldera is completed (more than 90 outcrops have been analyzed in the field) and
  - a GIS-based 3D model is under construction, including borehole and available geophysical data to understand the relationships between active and inherited brittle structures, volcanism and geothermal fluid flow. Magma resurgence processes are considered as a possible process to explain the present structural setting within the caldera, thus influencing the local deformation and permeability distribution.

X-ray Computed Tomography have been applied on selected rocks samples representative of the main geothermal reservoirs of Los Humeros and of the fossil analogue of Las Minas in order to obtain information on their primary porosity. In particular, andesite, Mesozoic limestone and an intrusive acidic rock have been analyzed.

A mineralogical characterization of the alteration facies associated with active and fossil fracture systems surveyed in the field is under study. **Stratigraphic and petrological studies on samples** related to the entire volcanic history at Los Humeros including the most recent magmatic events are on course and the results will give us information on the depth and origin of the present magmatic heat source. Samples for **petrological and alteration studies** are stored at UNIROMA and UNAM. An updated stratigraphy of the caldera fill has been reconstructed by fieldwork by personnel of UNIBA and CNR. In both institutions thin sections for further analyses have been already worked up. Some samples, collected during field work, have been also selected **for isotopic analyses and datings (Ar/Ar method)**; irradiation will be performed in next months.

Stratigraphic field survey at 1:25,000 scale and sampling on the Western sector of the caldera floor generated an **updated geological map of an area of more than 30 km2**, including some of the most recent volcanic activity of the area of the caldera complex. This survey has been also used to locate outcrops for archaeomagnetic sampling. **Archaeomagnetic sampling (230 samples from 9 sites)** was performed on January 2018, devoted to the age determination of the youngest terms of the reconstructed statigraphical sequence, and samples are presently under analysis. Laboratory analysis of samples of very recent olivine basalt lava flows and selected fallout deposits study are on course for the reconstruction of the volcanological processes during the evolution of the caldera complex.

The hyper-spectral scans of Los Humeros cores, conducted by CIPR along with CFE personnel, will be processed in the upcoming months to show the variation in mineralogical.

An **UAV with thermal camera was flown** at Los Humeros in February, covering several areas within the caldera. Images are to be processed, yet. However, it is already possible to clearly see 1-5m wide areas of enhanced heat flow around gas vents (warm spots up to about 30°C) in the northern part of the field. They appear to be aligned, which hints at fault-controlled heat/gas flow.

Finally, **morpho-structural lineaments analysis and** fieldwork (more than 100 outcrops have been analyzed in the field), has allowed the inference of the orientation (mainly NW-SE and SW-NW trending) and location of regional shear zones linking the geothermal field to the surrounding areas, where the meteoric recharge is occurring. Also, **kinematic indicators on brittle structures in the substratum have been collected** in the field, to reconstruct the evolution of the regional and local stress field. The identified active or inherited shear zones will be further investigated as suspected to represent the structural conduits channelling the meteoric water to the geothermal area. Here, the enhanced permeability (due to the interplay between regional and caldera collapse structures) favours the geothermal exploitation.

All results will be passed along to WP6 and WP8 for the development of the reservoir models. **Activities and results have been presented** at internal project meetings and stakeholder events.

2.4.2.2 Acoculco

The revision of the existing bibliography benefited of recent studies carried out by our Mexican colleagues. They produced a new geological map of the area, highlighting the volcanic evolution of the Acoculco area. This map was used as a base for our studies.

In the first reporting period, Acoculco has thus far been investigated through **6 fieldwork activities** (almost 7 days each) and **laboratory analysis (rock-samples for petrographic studies and thin sections)**. The activities were dedicated to:

- checking the mapped geological structures;
- collecting structural and kinematic data along brittle shear zones;
- at key outcrops making detailed analyses of spatial fracture properties using scan lines and drone imagery, for estimating permeability;
- analyzing the area where the borehole(s) for the EGS studies are located.

Fieldwork permitted to recognize two main fault zones, NW-SE and SW-NE trending respectively. Such shear zones display mutual crosscutting relations, although having different kinematic behaviour: dominantly normal, for the SW-NE trending faults, and from strike-slip (1st kinematic event) to right-lateral oblique-slip (2nd kinematic event), for the NW-SE trending faults. These two different systems can be explained in the same regional stress field, interpreting the NW-SE systems as transfer zones, active during the ongoing extension.

Key-outcrops were photographed in detail by drone and **converted by photogrammetry into 3D virtual-outcrop models**. These, combined with **structural scan-lines of fracture density**, width and length, provide a detailed field-based analysis at the cm to m scale of the 3D fracture distribution and permeability estimation will be derived in forthcoming months and will be provided for the reservoir models of WP6 and WP7. Finally, detailed fieldwork was concentrated also close to the area where the CFE boreholes are located, the ones that will be considered to perform simulations to test and establish EGS. The study through the area permitted to recognize that:

- the boreholes are located on the footwall of a SW-NE oriented normal fault, thus resulting dry and hot;
- the distance from the borehole to the permeable zone increases to depth, but at surface, it is estimated to be about 200 meters;
- the main fault zone close to the boreholes is supposed to be active, since the soil is deformed and active gas emissions are recorded.

The results of this study have been taken in account for the forthcoming geophysical and geochemical studies. Finally, PGI-NRI team is currently performing **U-Pb isotope, geochronological and paleomagnetic studies** for eight samples (collected in January 2018) from different Acoculco inside-caldera volcanic successions.

2.4.3 Geochemical characterization and origin of cold and thermal fluids

The task 4.3 was divided in different subtask as follows:

- 4.3.1. Fluid flow paths;
- 4.3.2. Geochemical characterization of fluids and hydrogeology;
- 4.3.3. Diffuse degassing and emanation;
- 4.3.4. Geochemical modelling;
- 4.3.5. HT tracer;
- 4.3.6. Fluid-rock interaction.

2.4.3.1 **Subtask 4.3.1 Fluid flow paths**

The goal of this subtask is to address the integration between field structural and geochemical data, meaning the integration of results from Task 4.3 with Task 4.2.

The activity was based on teleconferences with the involved researchers, addressing the on-going achievements, often in cooperation with colleagues from other WPs, especially from WP3. Similarly, deep discussions were carried out during GEMex technical meetings.

About Los Humeros, preliminary geochemical data (as it will be described in the following sections) suggest that the meteoric recharge areas are located in the regional surroundings of the caldera. Hence, regional structures playing the role of structural channels and connecting the recharge areas to the geothermal exploited areas, are necessary. By this, the issue focusses on which field methodology could be applied to get information from the surface, although a wide, thick and mechanically homogeneous ignimbrite is covering outcrops substratum.

The location of few geothermal manifestations (i.e. water temperature above the average value in boreholes) outside the caldera area, once more indicates the occurrence of structural channels favouring the flow of deep waters, even through the ignimbrite. As a consequence, a morpho-structural approach was proposed, studying the distribution of the regional tectonic lineaments from satellite images, both in the caldera area and in the regional surroundings. The results (described in 2.4.2.1) are preliminarily suggesting two main structural trends, NW-SE and SW-NE oriented, accounting for channelling the fluid path toward the caldera area, where the more intense deformation stored the fluids.

Differently about Acoculco, the issue is focussed on the main structural setting affecting the study area and, particularly, the structures affecting the borehole surroundings. Since the geochemical study is presently on its initial stage (collection of data), the fluid path is here only inferred on the basis of field-structural information, suggesting that the intersections between NW-SE and SW-NE fault systems enhanced the necessary local permeability.

2.4.3.2 Subtask 4.3.2 Geochemical characterization of fluids and hydrogeology

Literature review

The collection of geochemical data for cold and thermal fluids was performed in Los Humeros (LHGS) and Acoculco (AGS) geothermal systems. Sampling sites were selected checking the scientific literature published in international and "Mexican" journals and also taking into account information coming from the CFE. The revision of literature is completed and the data obtained are integrated with new ones. The collected data regard: chemical and isotopic characteristics of cold and thermal springs, water wells, surface water, geothermal fluids and natural gas manifestations (gas vents and diffuse degassing).

The main BRGM objective in this task is to develop auxiliary chemical and isotope geothermometers like Na-Li, Na-Rb, Na-Cs, K-Sr, K-Mn, K-Fe, K-F, K-W and δ18OH2O-SO4, in order to better know the deep reservoir temperatures in High-Temperature (HT) volcanic areas such as Los Humeros and Acoculco. Preliminary literature review has been carried out by BRGM with the collaboration of the other partners, especially the Mexican partners (CFE, etc.), in order to collect the main geological information and most of the geochemical data of the fluids sampled from Los Humeros deep wells and from thermal Acoculco springs.

From the existing literature data, only the deep temperature values estimated using the Na-Li auxiliary geothermometer could be compared with those given by the classical geothermometers and those measured at the bottom-hole.

Field work

IGG-CNR, in collaboration with CICESE, University of Morelia and University of Guanajuato, performed in the LHGS (03th-16th June 2017) a very detailed hydrogeochemical study mainly aimed to define the chemical and isotopic characteristics of cold and thermal waters and geothermal gases in order to identify the feeding areas of the LHGS, constrain the equilibrium temperature reached by the fluid at depth and identify the secondary processes (i.e. phase separation, precipitation of mineral phases). Big effort was dedicated to the identification and selection of cold springs located outside the Los Humeros caldera, suitable to study the local relation between stable isotope compositions and mean infiltration altitude of meteoric waters. Fifty-five water samples were collected during the geochemical survey (34 cold springs, 15 cold wells, 2 small lakes (maar), 2 thermal springs and 2 reinjection wells). Chemical and isotopes analysis are completed (Li^+, Na^+, K^+, Mg^{2+}, Ca^{2+}, B, As, SO_4^{2-}, Cl^-, NO_3^-, F, dissolved monomeric SiO_2, $^{18}O/^{16}O$ and the $D/^1H$ isotope ratios and the information obtained by preliminary interpretation was used to address the second field trip in LHGS performed in March 2018.

The very first geochemical fieldwork at the Caldera of Acoculco was performed by the IGG-CNR and the University of Florence (26th of January to the 4th of February, 2018). The main purposes of the measurement campaign were to:

1) Identify the spatial distribution of diffuse soil CO_2 flux and their correlation with the main fault/fracture system (for further details see paragraph of the subtask 4.3.3);
2) Sample both cold and thermal springs and the local (Los Azufres and Alcaparrosa) gas emissions for analyzing their chemical and isotopic characteristics to define the fluid source(s).

During the field trip in Acoculco, 51 water samples from thermal and cold discharges, and free and dissolved gas samples from bubbling pools (3) and thermal springs (1) were collected. Most of the chemical and isotopes analysis of waters (Li^+, Na^+, K^+, Mg^{2+}, Ca^{2+}, B, As, SO_4^{2-}, Cl^-, NO_3^-, F, dissolved monomeric SiO_2, $^{18}O/^{16}O$ and the $D/^1H$ isotope ratios) and gases (CO_2, H_2S, Ar, O_2, N_2, CH_4, $\delta^{13}C$-CO_2) are finished and in the next month it will be completed.

A few gas and water samples were also taken by BGS in January 2018. Analysis and interpretation are ongoing.

BRGM has also prepared a campaign of fluid sampling and on-site measurements in the Los Humeros (from deep wells) and Acoculco (from thermal springs) geothermal areas, with the collaboration of CNR and Mexican teams (UMSNH, CFE colleagues) from March 20 to 31, 2018.

Internal communication

Multiple teleconferences with different European and Mexican partner and also CFE on planning and organization of field work activities took place.

Presentations were given and discussions took place at all project internal meetings.

Results

Chemical characteristics of water samples from cold and thermal springs and wells in LHGS gave an important indication regarding the water/rock interaction processes (interaction with limestones formations, andesite rocks, ecc.). Isotopic characterization of collected samples from cold springs allows to obtain information regarding the altitude vs dD‰ (d^{18}O‰) local relation. These findings represent a novelty for LHGS and suggest that different “feeding zones” seem to be present, giving the chance to identify the main altitude of feeding zones of the geothermal system. Further investigations are necessary and the second field trip in LHGS is properly addressed.

Variable compositions from Ca^{2+}–SO_4^{2-} or Na^+–SO_4^{2-} (acid or near-acid waters from the Acoculco Caldera) to Ca^{2+}–HCO_3^- or Na^+–HCO_3^- (especially from outside the caldera), were observed in AGS. Acidic waters rich in SO_4 are probably due to the interaction between meteoric water and gas rich in CO_2 and H_2S present in main natural gas manifestations. Waters Ca-HCO_3 and Na-HCO_3 are originated by water-rock interaction process between limestones and/or andesite rocks, respectively. Chemical and isotopic data are in progress.

2.4.3.3 Subtask 4.3.3 Diffuse Degassing

Literature review

As an initial step a comprehensive literature and data review was performed to define the target area for a CO2 flux scouting survey. Focus of this literature and data review was in particular on structural-geological data, areas with geothermal surface manifestations, existing soil gas data, location of the central production field, etc.

Field work and Lab work (Los Humeros)

A planning field trip was performed in March 2017 to prepare the CO2 flux scouting survey.

Objective of the CO2 flux survey performed by GFZ from May to June 2017 was the identification of areas characterized by anomalous CO2 degassing, which should serve as a profound database for a more comprehensive soil gas survey covering a larger variety of different soil gases. For that reason a large area of ~6x4km was covered by approximately 2600 CO2 flux measurements based on the accumulation chamber method. Sampling was performed along profiles perpendicular to the major strike direction of the encountered structures. In addition, 10 samples for carbon isotopic analysis have been collected from anomalous CO2 flux areas for a better understanding of the source of the CO2 flux anomalies.

The preliminary results gave indications of various areas of increased structural permeability. A preliminary CO2 flux map served as the basis for

1) a soil gas survey by BGS focusing specifically on some areas with CO2 flux anomalies,
2) the design of the flight paths for a drone-based infrared survey,
3) the planning and grid optimization as well as technical optimization of used devices for an area-wide soil gas survey, and
4) the optimum placement of a long-term monitoring station for CO2 flux measurements from April-October 2018.

Another parameter measured during this initial survey was the natural local dose rate in the central production field for further tests of their applicability in geothermal exploration. Specific nuclides will be selected from the dataset for further processing and comparison to other soil gas parameter.

A larger gas survey was done at Los Humeros in Feb 2018 by BGS. Analysis and interpretation are ongoing. BGS focused on 4 areas within the broader region surveyed by GFZ 2017. BGS main aim was to focus on a much denser arrangement of soil gas and gas flux measurements across areas of known or presumed faulting, with a view to trying to locate individual vents. Some 330 sites were studied for flux/composition, and 50 sites for isotopes. Also, BGS deployed a rapid survey tool for measuring CO_2 concentrations in the air just above the ground - several 1000s of measurements were made with analysis spacing down to about 1m – individual gas vents were clearly identified.

During March 2018 measurements of CO2 diffuse degassing and sampling of gases from natural manifestations in LHGS are performed by IGG-CNR.

Field work and Lab work (Acoculco)

In January 2018 the IGG-CNR and University of Florence performed measurements of CO_2 diffused from soil in the Acoculco area. The φCO_2 values were measured at 418 sites within the Acoculco

Caldera (areas affected by tectonic feature and also sites named Los Azufres, Alcaparrosa and “Lagunilla”) using the Accumulation Chamber (AC) method.

The preliminary results indicate that:

- CO_2 flux anomalies depending on preferential tectonic lines were not observed;
- low CO_2 fluxes were measured (ranging between 0.12 and 48.9 g m^{-2} day^{-1}), implying that most data were associated with soil respiration.

Internal communication

Multiple teleconferences on data review and planning of field work activities, organization, further involvement of additional partners in the Mexican consortium (Loic Pfeiffer, CICESE).

Presentations were given and discussions took place at all project internal meetings.

2.4.3.4 Subtask 4.3.4 Geochemical Modelling

Regarding the geochemical modeling, ISOR performed the following activities:

a) development of a new program for chemical speciation and reaction progress calculations called RockJuice. As it was decided earlier – most of the budget attributed for ÍSOR (WP 4), 24 person/month, has been attributed to the computer program development. The progress of 25% has been calculated based on the amount of hours spent on the computer code development since October 1st. According to the author of the computer code, there might be a problem to finalize the program before the end of month 24, however, we can not predict at this stage how the code development will progress.
b) review of the CFE data with the boreholes chemical composition, temperature and pressure logs
c) the deep fluid has been modeled using the chemical speciation program WATCH (Arnórsson et al., 1982, Bjarnason, 2010) on the basis of the analyzed chemical composition of the steam and liquid phase given by the CFE.

The geochemical modelling carried out by IGG-CNR on the geochemical data provided by CFE, on fluid sampled at well head, follow a complex procedure with the aim to reconstruct the fluid composition at well bottom. A further step is to use the reconstructed fluid, representative of the system, to investigate the possible precipitation of secondary phases and check the behaviour of geothermometers against the measured temperatures. The procedure use geochemical modelling codes (WATCH, CHIM-XPT) to reconstruct the fluid composition at well bottom with the aid of a specific wellbore simulator (WELLSIM, HOLA) to better describe phase segregations in terms of steam/liquid ratio and CO2 partitioning.

An advanced geochemical model were carried out by means of CHIM-XPT, to compute pH at depth and have temperature evaluation using the theory described in Reed and Spycher 1984. The possible precipitation of secondary minerals was investigated as well.

Internal communications

The introduction to the new computer code has been presented during the GEMEX 2nd General Assembly in Akureyri 2-3 October 2017.

2.4.3.5 Subtask 4.3.5 Development, qualifying and application of high-T tracers

IFE performs the study regarding high temperature tracer. Of seven tracer candidates tested for static thermal stability up to 250°C, three were regarded as sufficiently stable to qualify for further stability and flooding property tests. The three candidates (Tracer A, B and C) were tested for thermal stability in closed quarts vials at temperatures up to 350°C. When Basalt was not present, the recoveries were near 100% for all the three candidates. When Basalt was present, the recoveries of Tracer A and B were considerably reduced, while the recovery for Tracer C remained unchanged. Flooding experiments were performed at temperatures up to 250°C using a column filled with Basalt rock particles. Tracer B was not recovered in the flooding experiments, Tracer A was slightly retained while Tracer C behaved nearly in the same way as the ideal tracer tritiated water. Tracer B was not regarded as suitable due to adsorption, and Tracer A was not suitable for the type of rock tested, but may perhaps be used for other rock types.

2.4.3.6 Subtask 4.3.6 Los Humeros geothermal field and fluid-rock interaction experiments

IGG-CNR and University of Florence perform the study related to fluid-rock interaction in LHGS. Andesitic rock from Tezuitilan Formation (50-150 μm granulometric fraction) has been selected as a starting material for the experiments. It has been characterized from mineralogical point of view and a whole rock analysis is in progress. Moreover, water sampled in Cofre de Perote and supposed to be representative of pristine fluid circulating in andesitic reservoir has been chosen as liquid reactant.

A series of fluid rock interaction experiments under CO2 overpressure have been undertaken at 200-300 °C in order to monitor solid and liquid changes due to the interaction. All experimental runs were performed in an externally heated micro-reactor and the liquid/solid ratio was arbitrarily chosen to be ~16. Another series of experiments will be executed in the next months at the same T using a different solid as starting material

2.4.4 Publications

Carrasco-Núñez, G., Bernal, J. P., Dávila, P., Jicha, B., Giordano, G., & Hernández, J. (2018). Reappraisal of Los Humeros volcanic complex by new U/Th zircon and 40Ar/39Ar dating: Implications for greater geothermal potential. *Geochemistry, Geophysics, Geosystems*. DOI: 10.1002/2017GC007044

2.4.5 Dissemination activities (talks, posters, workshops)

Groppelli, G., et al., New geological, structural and volcanological data of the Los Humeros Volcanic Complex: implications for reconstruction of the 3D model volcanic structure and geothermal exploration. IAVCEI Conference, Portland, USA, 14-18 August 2017

Jentsch, A., et al., Structural-geological impact on soil gas composition at Los Humeros Volcanic Complex, IMAGE Final Conference, Akureyri, Iceland. 4-6 Oct. 2017

Liotta, D., et al., State of the art of WP 4 after one year of GEMex , GEMex Stakeholder Board meeting, Brussels (Belgium), 15 Nov 2017

Liotta, D., State of the art of the GEMex WP4: Tectonics and fluid flow. GEMex information event, Pisa (Italy), 27 Mar 2018.

Muller, J., Laboratory Studies of Geothermal Tracers at Supercritical Conditions. GeoEnergi2017 – Geothermal Conference, Bergen (Norway), 22-23 May 2017

Olvera-García, E., The Las Minas exhumed geothermal system (Veracruz, Mexico): a proxy for the Los Humeros geothermal field. European Geothermal PhD Day, Zurich (Switzerland), 15-16 March 2018

Wheeler, W., et al., GEMex- Europe-Mexico collaboration for development of Enhanced Geothermal Systems and Superhot Geothermal Systems. GeoEnergi2017 – Geothermal Conference, Bergen (Norway), 22-23 May 2017

2.4.6 Patents

A patent has been filed for the tracer candidates and will be published in June 2018.

2.4.7 Deviations from the Description of Action

Task 4.2: Isotopic analyses on the altered core-samples of Los Humeros geothermal wells are delayed as these samples have only recently arrived in Europe and they will be used for other analyses before they can be made available for isotopic analyses. If the samples are sent to the CNR within 3-4 months the isotopic analyses will be carried out within the project extension period.

Only one sample of the mafic dikes collected by CNR in the basement surrounding the Los Humeros caldera is fresh enough to allow radiometric dating. The sample have been hand-crushed and sieved, and the groundmass (fraction 250÷355 µm) has been separated using magnetic methods followed by handpicking under a binocular microscope. The radiometric analysis is in delay as the 40Ar-39Ar laboratory at CNR-IGG is currently under maintenance. The analysis will be scheduled as soon as the laboratory equipment will become fully operational and the analysis will be carried out within the project extension period.

Task 4.3, Subtask 4.3.2: At the beginning stage of the project, the activities were delayed due to internal issues on the Mexican side (multiple changes of task leaders, financing issues, etc.). Also, during the sampling campaign (carried out by IGG-CNR) on 2017 in LHGS, customs authority (Guadalajara airport) retained all scientific equipment shipped from Italy, obstructing the import processing and the regular schedule of the planned work. The process to recover the equipment was extremely delayed due to lack of communication between Mexican Airport Customs and Mexican partner involved. Now, the equipment seems to be missed and its searching process represents a very difficult challenge. Even if the equipment is still retained by the Mexican customs, the planned activity for 2017 was complete and is ongoing for 2018.

The approximate progress of the BRGM contribution in task 4.3 until now is close to 10%. Relative to the planned schedule, the BRGM activities have been slowed down, given that the campaign of fluid sampling has been delayed from 6 to 7 months, but this deviation is still acceptable.

2.5 Work Package 5: Detection of deep structures

Lead: ISOR
Partners: CIPR, CNR, CRES, GFZ, HBO, ISOR, KIT, OGS, TNO, UU
Duration: month 1-44
Status: started and ongoing

Objectives:

The development of seismic and resistivity methods for high temperature geothermal fields have been the subject of the former and ongoing FP-6&7 supported projects I-GET and IMAGE. The objective of this work package is to further advance the methodology and test it by application to two high temperature systems in Mexico: the superhot conditions at depth in the Los Humeros field and the Acoculco EGS field. The existing models from two superhot fields in Iceland (Krafla and Reykjanes) will also be revised by applying improved methodology and results from the two first deep drilling projects in Iceland, IDDP-1 in Krafla and IDDP-2 in Reykjanes. The improved models from these fields will be compared to the Mexican fields. In addition, the results from GEMex will be compared to available results from high temperature fields in Indonesia and Africa.

Participant number	1	2	3	5	7	11	12	13	17	19	**Total**
Short name	GFZ	ISOR	TNO	UU	CNR	CRES	OGS	CIPR	KIT	HBO	
PM foreseen in total GEMex	45	54	20	41	8	22	24	24	45	36	319
PM used	13.5	38.5	4.65	16.91	4.04	4.25	14.2	6.4	17.66	14.9	134.9

Table 10: Status quo of personal resources WP5

GEMex takes advantage of a large variety of methods being applied at the same location with a lot of different methods applied with regard to data analysis. This provides an excellent opportunity for the comparison of methods and the integration of different datasets.

The geophysical work in both geothermal sites suffered from the late provision of the Mexican funding, since all work is planned in strong collaboration with the Mexican partners. Therefore the fieldwork started later than initially planned. However, in the first reporting period, a lot of the geophysical work has started and is going to be completed in 2018. Figure 9 show the measurement points for gravity and resistivity as well as the station locations of the passive seismic network installed at Los Humeros.

Data analysis is only starting, however preliminary results from the resistivity survey in Los Humeros have already been shared with the project consortium.

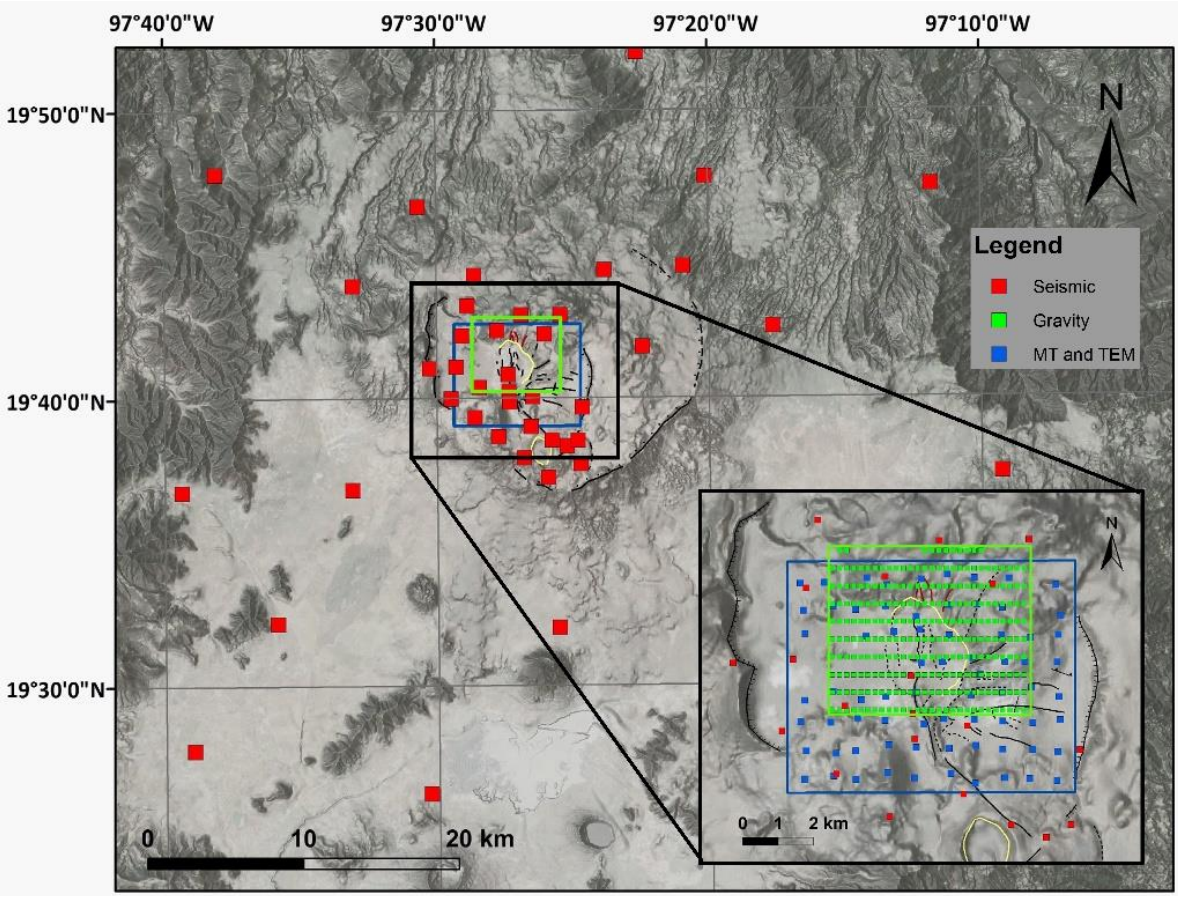

Figure 9: Location of measurement point for gravity and resistivity survey and for passive seismic stations in Los Humeros

2.5.1 Task 5.1 Resistivity imaging of EGS and SHSG

2.5.1.1 Subtask 5.1.1: Synthetic model calculations to optimize the results of 3D MT/TEM modelling and avoid artefacts (ÍSOR, CNR)

MS27 "Synthetic resistivity model calculations completed" has been reached in time.

Deliverable 5.1 on synthetic model calculations to optimize the results of 3D MT/TEM and avoid artefacts was written by ÍSOR, CNR and KIT and delivered in December 2017 (available on the website: https://goo.gl/AsEyYp)

In the deliverable, efforts were undertaken to further the understanding of the underdetermined problem of inversion of resistivity data, i.e. by investigating how to regularize the inversion with external constraints. The work carried out was a continuation of previous efforts with an emphasis on how data from high-temperature geothermal fields could look like, which artefacts emerge and what is the way forward from where we stand today.

The deliverable is composed of three parts i) synthetic data created from a generic high-temperature geothermal system, ii) synthetic data created for the Acoculco geothermal area in Mexico and iii) investigation of the influence of fault systems on the magnetotelluric data.

2.5.1.2 Subtask 5.1.2: Review and QC of existing data from Mexican sites (ÍSOR)

ÍSOR received TEM and MT data from Los Humeros through CFE and quality checked them. Some of the data, their inversion and interpretation are discussed in a recent paper published in Geothermics by Arzate et al. (2018). In general the data are not of a good quality but aided in making a resistivity survey plan for Los Humeros. Some of the soundings might be used in the 3D inversion of the resistivity data for the area.

The Vertical Electric Sounding (VES) from Acoculco were reviewed and used by CNR for task 5.1.1.

2.5.1.3 Subtask 5.1.3: Survey design and preparation for additional measurements in Acoculco and Los Humeros (ÍSOR, CNR, KIT)

A resistivity survey plan for Los Humeros and Acoculco was drafted for the first time in Morelia at the kick-off meeting in October 2016, jointly by the European and Mexican partners. The discussion was ongoing for the next few months. Based on the already existing data from the two areas (Task 5.1.2), the synthetic model calculations (Task 5.1.1) and other more recent geoscientific results from the areas within GEMex, the proposed survey plan was discussed between all the collaborators and approved at the meeting in Akureyri, Iceland in October 2017.The plan was shown to CFE for their comments. Preparations for the coming field survey in Los Humeros as well as a timetable were discussed amongst the partners and decided on in several skype meetings. The first phase of the field work in Los Humeros was performed from November to December 2017 and the second phase is scheduled in April 2018. The plan for the resistivity soundings in the second phase was discussed and approved at the meeting in Bari, March 2018.

The survey plan for Acoculco was made in a collaboration between the Mexican and European partners, discussed a several skype meetings, the meeting on EGS in Potsdam in January 2018 and finalized at the European meeting in Bari in Italy, in March 2018. The survey plan for Acoculco proposed 75 sounding pairs. The orientation of the grid is parallell and perpendicular to the orientation of the main faults in the region and the center of the grid is where the EGS experiment is planned to take place. The field work is planned for four weeks in May 2018.

2.5.1.4 5.1.4: Acquisition of new MT and TEM data collection in both fields, field work and QC (ÍSOR, KIT)

During four weeks in November-December 2017 the first part of the resistivity field campaign was carried out in Los Humeros. The majority of the work was done by the Mexican partners, who took care of logistics, transportation and equipment. A team from the European side (ISOR and KIT) joined in part of the field work. The campaign and the collaboration between the two sites was smooth and most successful – a learning full process for everyone. The team communicated daily with CFE and the local community during the field campaign. Some 50 TEM soundings and 75 MT soundings were collected – most of them of good quality. **Fehler! Verweisquelle konnte nicht gefunden werden.** shows the current status of the collected soundings and preliminary quality control.

In April 2018 (as this report is being written), the second part of the survey in Los Humeros is taking place where 60 MT/TEM sounding pairs and 25 TEM soundings (at the sites where TEM data were not collected in the first part) are collected. The plan for the resistivity soundings in the second phase was discussed and approved at the meeting in Bari, March 2018 based on the preliminary inversion of the data from the first phase and the more recent geoscientific results in GEMex.

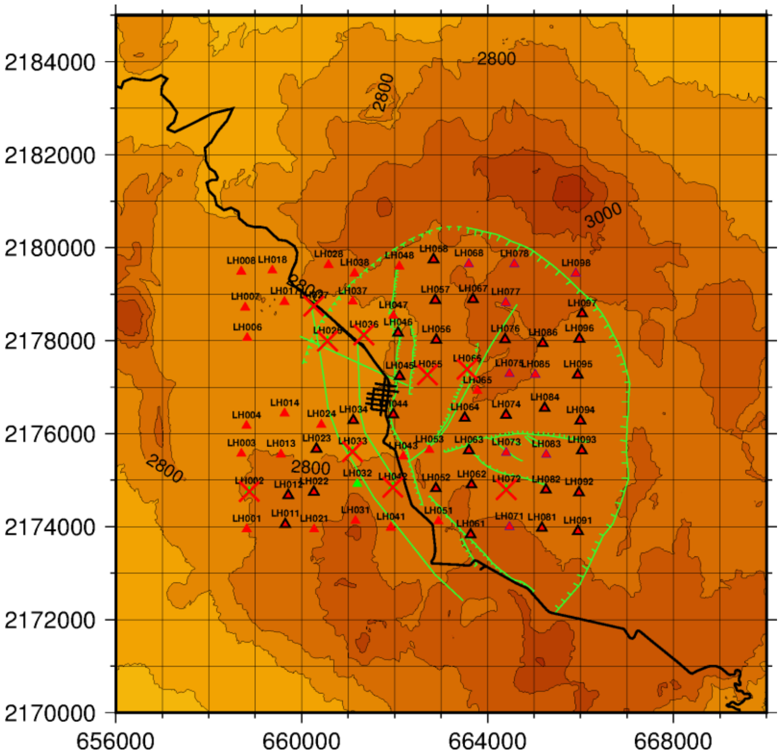

Figure 10: Status of the resistivity data acquisition in Los Humeros – first phase. Green lines are calderas and faults. Red triangles are sounding locations. Triangles with no border and with a border are soundings where only MT data are available respectively. Soundings with a red cross over are soundings with bad data quality

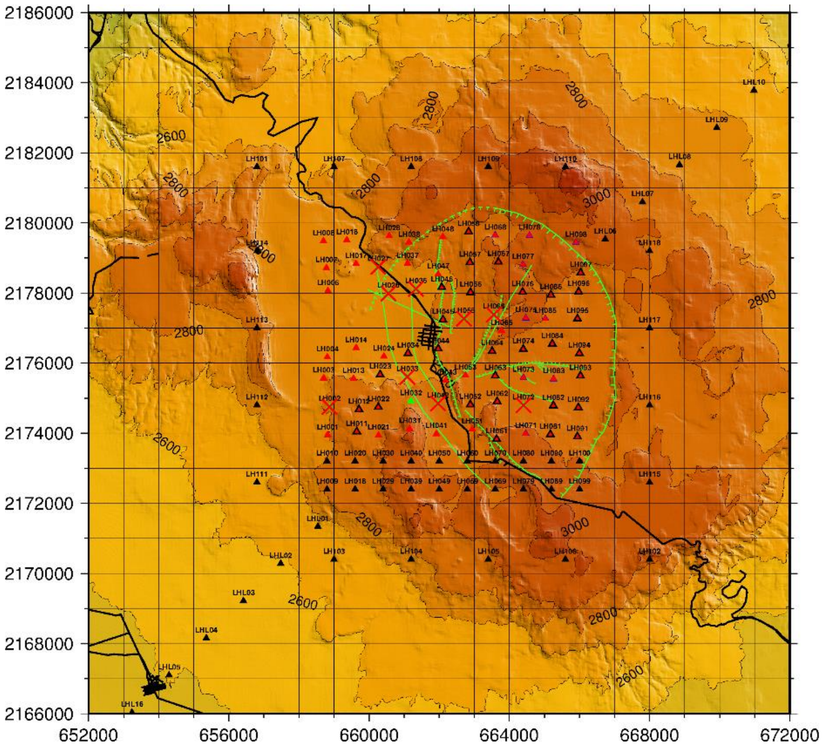

Figure 11: Second stage of the field work in Los Humeros. Black triangles denote the planned sounding locations.

2.5.1.5 **Task 5.1.5: Data processing and resistivity models (1D and 3D) of the Los Humeros and Acoculco fields (ISOR, CNR, KIT)**

Data processing of the TEM and MT data from the first phase of the Los Humeros resistivity campaign is well underway. Several different processing schemes have been tested, using the bounded influence remote reference processing (birrp), procMT, and WinGLink codes. Preliminary EDI files of good quality soundings have been used to to construct a preliminary resistivity model of the Los Humeros area based on 1D joint inversion of the TEM and MT data. Figure 12 and Figure 13 show a horizontal resistivity depth slice at 2,400 m a.sl. and a vertical resistivity cross-section through the model, respectively, for demonstration purposes only. More detailed models will be available when the field work is finished and the processing has been finalized.

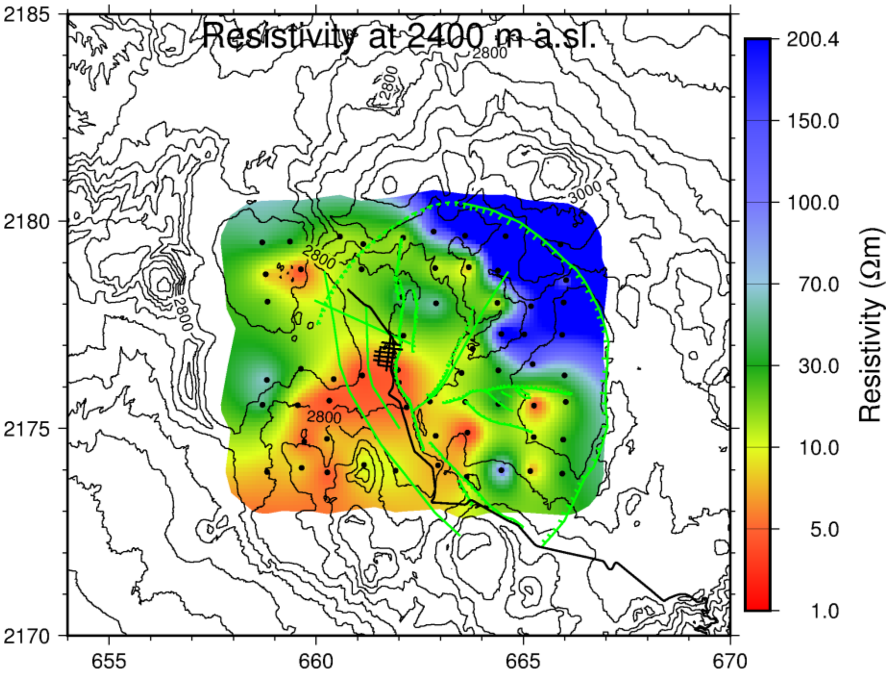

Figure 12: Horizontal resistivity cross-section through the preliminary 1D model of Los Humeros at 2400 meters above sea level. Black dots are MT station locations. Green lines are calderas and faults.

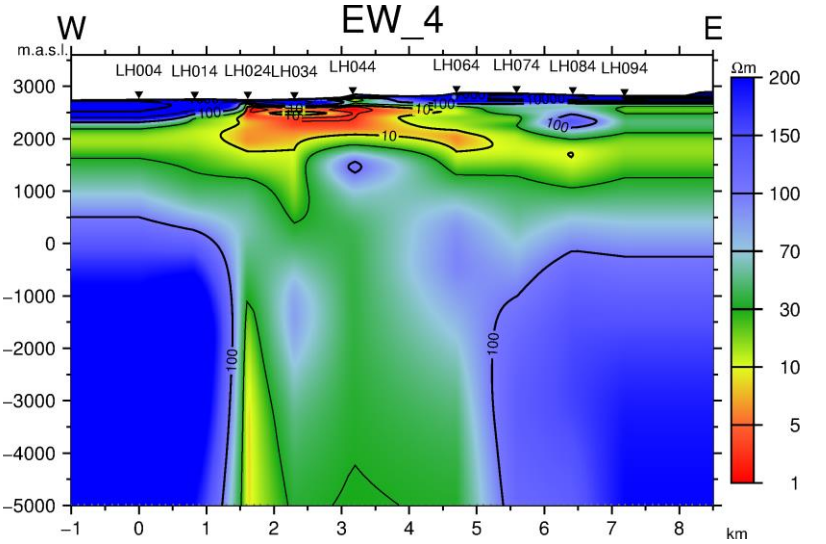

Figure 13: West-east vertical cross-section through the preliminary 1D resistivity model of Los Humeros.

2.5.1.6 Management and internal dissemination

Several meetings, workshops, teleconferences have been organized during the reporting period to reach the milestones and deliverables of Task 5.1, and to communicate beyond the task framework within GEMex. These actions are listed in the following.

- GEMex Kick-off meeting (Morelia, Mexico, 15-17/11/2016)
- GEMex European meeting (Utrecht, The Netherlands, 23-24/03/2017)
- GEMex General Assembly meeting (Akureyri, Iceland, 02-03/10/2017)
- GEMex European meeting (Bari, Italy, 12-13/03/2018)
- General teleconferences: Several teleconference were held during the reporting period. Minutes of these meetings are available on VRE:
- Los Humeros field campaign November 2017: Report from the field survey in Los Humeros
- Meeting at the end of the Los Humeros field campaign; 27/11/2017 ISOR, UNAM and KIT

2.5.2 Task 5.2 Seismic imaging

GFZ organized (M4) a workshop with all partners in Potsdam (Germany) in order to define the procedure and the implementation of the description of work. Each partner gave a presentation on what they did in the past what and how they are going to do within GEMex.

2.5.2.1 Subtask 5.2.1: Data acquisition

All partners contributed to the gathering and evaluation of existing passive and active seismic methods and the design of the new acquisition network in Los Humeros for passive monitoring based on the objectives and the instruments available. Due to the difficulties associated with authorization to access Acoculco, it was decided that Los Humeros would see the deployment of the main instrumentation first. Activities at Acoculco were postponed.

In agreement with the Mexican partners, the European stations will stay in Los Humeros. Approximately 15 stations from the Mexican team will be deployed in Acoculco.

Task 5.2.1a) Gathering and evaluation of existing passive and active seismic

After OGS initial active existing seismic data request to Mexicans, OGS performed an analysis of geological and geophysical well data using information available in literature and information received from Mexicans, in order to update the geophysical model utilized to simulate the seismic waveform propagation with temperature (including melting and possible supercritical conditions). OGS received logs of wells H42 and H43 (Los Humeros), performed log editing and analysis of Vp, Vs and Vp/Vs, covering a limited depth range. OGS also received Los Humeros seismic-line digitized data from Mexicans (CFE data from UNAM), for lines L5, L2, L3 and L4. OGS data processing included formatting, geometry, pre-processing and editing, quality control. The processing is in progress for L5, and in initial preparation phase for L2, L3 and L4. L5 data processing includes shallow model tomography from shot's first breaks, static correction, velocity analysis, CMP stack, signal improvement and data migration. Preliminary interpretation of structural events on provisional results was performed.

Task 5.2.1 b) Design of new acquisition networks for passive monitoring and based on the objectives and instruments available

GFZ worked intensively on setting up a methodology for network design, with application to the Mexican network. The results and the method are submitted to JVGR. OGS contributed to the final evaluation of seismic acquisition network design in Los Humeros, for tomographic inversion reliability purposes (continuation after Utrecht meeting).

Task 5.2.1 c) Deployment and acquisition of new data using short-period and broadband seismometers

Regarding the instrumentation, HBO provided 3 broad-band seismometers. GFZ (Geophysical Instrumental Pool of Potsdam) provided 40 seismometers (20 broadband Trillium compact seismometers and 20 short-period Mark-sensors) and 43 dataloggers (20 EDL and 23 Data-cube) and 43 solar panels). All instruments were deployed by GFZ and the Mexican partners (University of Morelia and UNAM).

GFZ set up an ftp server to allow the partners downloading the passive seismic data that the Mexican upload once they have collected them in the field (on a regular basis).

2.5.2.2 Subtask 5.2.2: Seismic structure (tomography methods) of the geothermal fields and their surrounding

As the data have only just been recorded, data analysis is just starting.

a) Earthquake analysis: KIT performed an archive of the Los Humeros passive seismic data (up to Feb. 18), and get prepared for detection and picking of induced earthquakes.

b) Travel-time tomography: GFZ and KIT discussed the way to analyze the data, in terms of detection parameters and algorithms. For the purpose of this subtask, OGS prepared and uploaded on VRE the initial 3D geophysical regional and local models of Los Humeros, starting from WP3.1 model results and using compressional velocity and formation data from literature (3D velocity grids uploaded on VRE). ISOR worked on setting-up TomoDD for preparing the tomographic inversion.

c) Ambient noise correlation methods: TNO internal discussion on the details of the data processing work-flow was performed.

d) Attenuation: Even if foreseen in 5.2.2d, at the moment no borehole seismic data (VSP) are available, therefore, not usable for seismic interferometry with body waves at depth from active sources (5.2.2c) and attenuation analysis (5.2.2d) as initially expected.

e) Beamforming: HBO developed tools to analyze the acquired seismic data from Mexico which are ready to use and already tested on several datasets: A parallelized beam-forming algorithm based on Matlab to identify the speed and direction of surface and body waves was developed. The tool was tested among others on a dataset in North America (Parkfield) with the emphasis on anisotropic observations.

2.5.2.3 Subtask 5.2.3: Time-dependent processes within the structures

As the data have only just been recorded, data analysis is just starting.

d) Time lapse study: HBO developed a Python-based GUI to perform the proposed time-lapse study of passive seismic attributes caused by partially saturated rocks. This GUI is tested on a local dataset from Bochum. Moreover, a synthetic time reversal modelling study was conducted to locate and characterize microseismic events. We are in the process of publishing the results.

2.5.2.4 Subtask 5.2.4: Modeling

a) Methods: HBO implemented a high-performance wave-propagation modeling code on a large-scale computer at the Jülich Supercomputing Centre (JSC), Germany.

c) Full-waveform modelling: OGS performed a sensitivity analysis on dependence of elastic properties on temperature and pressure conditions, approach based on synthetic/numerical models (submitted paper “Sensitivity of seismic properties to temperature variations in a geothermal reservoir” to Geothermics) (also for the purposes of T5.4). OGS also performed a full-waveform seismic modeling with temperature using an initial model derived from literature (Presented during Akureyri GA, 2017).

2.5.3 Task 5.3 Evaluation of other geophysical data

Results of Task 5.3 will provide information on deformation (T5.3.2) and fracture porosity (T5.3.1) of the expected reservoirs at Los Humeros and Acoculco. T5.3.1 data will be used in T5.4. for joint inversion with magnetotelluric data. Furthermore, the results will have implications for WP6.

2.5.3.1 Subtask 5.3.1: Gravity and magnetics

a) Obtain available gravity data and check the quality for their use in Bouguer maps (KIT).

No data from previous gravity surveys have been obtained up to now. The data is available to the Mexican partners, but not to the EU part for confidentiality reasons. We are still in negotiations to also buy access to this data.

b) Add gravity stations as required. (KIT)

The survey design has been performed jointly by European and Mexican partners. One gravity survey has been conducted from 17 Nov- 16 Dec 2017 with major effort from the Mexican partners, who also provided the instrumentation. A researcher from KIT took part in the survey from 17 – 26 Nov. Gravity has been measured at approximately 280 locations in the same area as the resistivity survey (Task 5.1).

A second survey is planned for April/May 2018. The survey design and preparation has been completed.

c) Gravity and magnetic data modelling to provide constraint for joint interpretation. (KIT, UU, TNO, CRES)

- Set-up of GIS database including georeferenced geological and geophysical interpretation and existing data points, including gravity measurement points (in preparation of D5.6)
- Digitizing geological section for gravity forward modelling, concept of scenarios for fracture porosity, comparison with temperatures, collection of density data from other partners and literature, forward modelling of expected gravity effect for different scenarios of fracture porosity

Work in the first 18 months’ period progressed in parts as planned in the task, however, the fieldwork related work started with a delay of 6 months due to accessibility of the geothermal fields in Mexico. This lead to a delay of reaching Milestone M29 (planned to be reached in M12). By the end of this reporting period 50% of M5.3 has been reached (Figure 7 and 8). Note that full completion is planned to be reached in M20.

2.5.3.2 Subtask 5.3.2: GPS & InSAR (TNO, UU, ISOR)

a) Obtain InSAR data from satellites (TNO).

TNO and UU collected freely available C-band satellite data covering Los Humeros and Acoculco and selected the datasets suitable for processing. We performed PS-InSAR (Persistent Scatterer by Synthetic Aperture Radar Interferometry, Hooper et al. (2007)) time series analysis over the eastern sector of the Trans-Mexican Volcanic Belt with main focus on the Los Humeros and Acoculco geothermal fields. We used C-band Single Look Complex (SLC) Envisat ASAR and Sentinel-1A images acquired on descending orbits between 2003 March - 2007 February and 2016 October – 2018 January, respectively. Milestone 30 has been reached in time.

Satellite	Orbit	Study Area	Coverage	Number of Images	Track	Processed
Envisat	Descending	LH	20030308-20070313	22 (13 used)	212	Yes
Envisat	Descending	AC	20030216-20091206	31 (16 used)	484	Yes
Envisat	Ascending	AC	200302-201004	34	148	No
Sentinel-1	Descending	LH, AC	20161016-20180103	33 (33 used)	143	Yes
Sentinel-1	Ascending	LH, AC	20170312-20180130	17	5	No

Table 11: Data selected for PS-InSAR time series analysis. LH and AC stand for the images covering the Los Humeros and Acoculco geothermal fields, respectively.

b) Collect high precision GPS for calibration

Campaign-based GPS measurements were conducted by the Mexican partners starting in April 2017. Results of the first two campaigns are collected, but we have not yet received a description about the details of measurements and corrections. The two campaigns took place in April-May 2017 and in September 2017. 14 GPS stations were deployed in total, 6 for Los Humeros and 8 for Acoculco. Further campaigns are expected to come and movements based on the GPS data will be compared with InSAR results in the upcoming reports.

c) Analysis of crustal deformation by use of InSAR and high precision GPS data to identify reservoir compartmentalisation and sort out background vertical motions related to magmatism. Compare to similar results in superhot systems in Iceland (TNO, ÍSOR).

Processing was performed on Envisat ASAR and Sentinel-1A images with descending orbits covering Los Humeros and Acoculco. A singe master from each dataset was selected based on criteria for perpendicular and temporal baselines after Hooper et al. (2007). During the processing the interferograms were investigated and the ones with no visible coherence and perpendicular baselines above 500 m were discarded.

Based on the Envisat results the Los Humeros geothermal field is characterized by about 4-8 mm/year of surface subsidence (Figure 14b). The largest subsidence is observed in the Norther part of the field. On the other hand, these movements might be (partly) influenced by the atmospheric phase overprinting the deformation signal. Therefore, correction is required based on the calculation of stratified tropospheric delays. We are currently working on these corrections and the revised deformation maps will be documented in future reports of task 5.3.2.

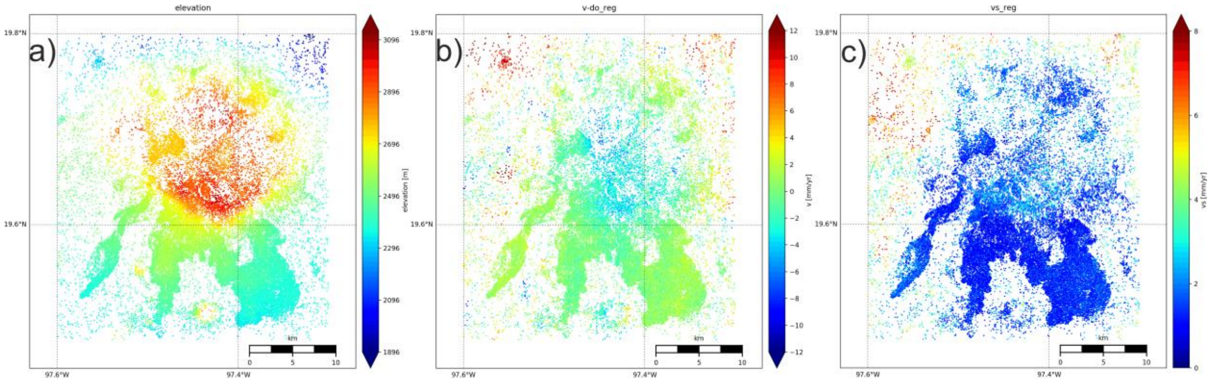

Figure 14: Elevation [m] (a), velocities relative to the satellite line of sight [mm/year] (b) and the standard deviation of velocities [mm/year] (c) over Los Humeros obtained by PS time series analysis of Envisat ASAR SLC products.

2.5.4 Task 5.4 Integration of methods and inversions constraints

As the data acquisition in the Tasks 5.1, 5.2 and 5.3 is still ongoing and processing has only started, the integration of methods has not yet started and work has mostly been restricted to theoretical considerations.

5.4.4: Interpretation of geophysical models in terms of geothermal parameters like temperature, porosity etc. Input from lab measurement of physical properties required (WP6.1) and structural maps (WP4.1).

OGS performed sensitivity analysis on dependence of elastic properties on temperature and pressure conditions, with an approach based on synthetic/numerical models (submitted GEMex paper “Sensitivity of seismic properties to temperature variations in a geothermal reservoir” to Geothermics, in review). OGS also performed elastic full-waveform simulation along the acquisition line L5 of Los Humeros, with comparison of simulations calculated by initial model derived from WP3 with velocity from literature and initial velocity model derived from seismic data.

5.4.5: Distribution of rock modulus of elasticity and correlation to temperature: Comparing the spatial distribution of rock modulus of elasticity with the temperature distribution data derived from the thermo-mechanical models during task 3.3, Derive deep formation temperatures from seismic and gravity surveys. (CRES, OGS).

CRES performed

- evaluation of formation temperature readings at Los Humeros from published and CFE data,
- development of simplified 1-D P-T models for Los Humeros,

- estimation of rock modulus of elasticity at Los Humeros from published literature,
- Investigation of suitable statistical models and development of 1-D correlations of T with Vp and µ for Los Humeros and Acoculco.

5.4.6: Utilize ensemble-based inversion methods facilitating uncertainty quantification

CIPR has further developed a framework for ensemble-based inversion, and implemented simulators for TEM and MT into this framework. An expanded abstract utilizing the upgraded framework on synthetic data has been submitted for consideration by SEG 88th Annual Meeting. CIPR has also evaluated different approaches to joint utilization of multiple geophysical data types for geothermal applications. Some thoughts regarding this were presented in the meeting in Bari. This presentation also pointed out the availability of the inversion framework for other project participants, and the desire from CIPR's side of obtaining seismic simulators from other project partners for implementation within the framework.

2.5.5 Publications

Poletto, F., Farina, B., Carcione, J. M., Sensitivity of seismic properties to temperature variations in a geothermal reservoir, Geothermics, submitted

2.5.6 Dissemination activities

Békési, E., Martins, J., Fokker, P., Bonté, D., Limberger, J., van Wees, J.-D., "*Active deformation of the eastern Trans-Mexican Volcanic Belt based on InSAR persistent scatterers*", Geophysical Research Abstracts Vol. 20, EGU2018-16136, EGU General Assembly 2018, Vienna (Austria)

Toledo, T., et al., "*Seismic network survey design and performance*", IMAGE Final Conference, Akureyri (Iceland), 4-6 Oct. 2017

Toledo, T. et al.: "Experimental Network Design for Earthquake Location Problems: application to geothermal field seismic networks", European Geothermal PhD Day, 14-16 Mar 2018, Zurich, Switzerland

Toledo, T., Jousset, P., Maurer, H., Krawczyk, C.: "Optimized Experimental Network Design for Earthquake Location Problems: applications to geothermal fields seismic networks", Geophysical Research Abstracts Vol. 20, EGU2018-15056, EGU General Assembly 2018, Vienna (Austria)

Tveit, S., Mannseth, T., "*Identification of geothermal reservoirs from ensemble-based Bayesian inversion of 3D MT data*", expanded abstract for SEG 88th Annual Meeting, submitted

2.5.7 Deviations from the Description of Action

Task 5.2:

Subtask 5.2.1 c) There is no activity planned so far concerning the DAS acquisition method. The reason for this is that the DAS acquisition was foreseen for the site in Acoculco in the assumption that a new well would be drilled. A DAS installation would only make sense if the cable would be deployed before/during the casing of the borehole because the measurement requires a good coupling of the cable to the drilled rock. This was not correctly communicated between the two consortia and it came to our attention only after the signature of the GA, that there will be no new drilling in Acoculco. Consequently, we do not see a possibility for DAS installation during the lifetime of the project.

The completion of Milestone 28 will be reached in M20 (as indicated in the amendment of the GA) The deployment of seismic stations in Los Humeros was already finished in M13 (only two stations were added in M18). However, we had no permission to install instruments in Acoculco until December 2017. Hence, all European stations have been installed in Los Humeros and it was agreed that the Mexican teams will deploy their newly acquired stations in Acoculco. The Mexican stations have only arrived in Perote in March and deployment is starting. 16 Mexican stations will be deployed by the Mexican team and data sharing with the European team as with the Los Humeros dataset is foreseen.

Subtask 5.2.2 d) Attenuation: Even if foreseen in 5.2.2d, at the moment no borehole seismic data (VSP) are available, therefore, not usable for seismic interferometry with body waves at depth from active sources (5.2.2c) and attenuation analysis (5.2.2d) as initially expected.

Task 5.3:

The completion of Milestone 29 will be reached in M20 (as indicated in the amendment of the GA): A second fieldwork in Los Humeros and Acoculco is scheduled from 12.4.2018 to 16.5.2018. This will include the final acquisition of the necessary “other” geophysical data. The deliverable will be reached in month 32.

2.6 Work Package 6:

Lead: RWTH
Partners: BGS-NERC, CNR, GFZ, ISOR, RWTH, TNO, TUDA, UFZ, UNITO, UU
Duration: month 1-32
Status: started and ongoing

Objectives:

In Work Package 6, the EGS reservoir in Acoculco and the SHGS reservoir in Los Humeros will be characterised with respect to rock and fluid properties and their variation with temperature and pressure. These are required, on the one hand, for setting up and parameterising discretised structural models used in static and dynamic numerical simulations of fluid flow, heat transport, and phase behaviour before and during geothermal exploitation. On the other hand, rock and fluid properties and their variation with temperature and pressure are required for interpreting geophysical seismic and electromagnetic measurements on the surface.

Participant number	1	2	3	5	6	7	8	18	20	23	**Total**
Short name	GFZ	ISOR	TNO	UU	RWTH	CNR	TUDA	NERC	UNITO	UFZ	
PM foreseen in total GEMex	21	6	5	17	68	3	18	17.5	21	6	182.5
PM used	5	4.9	0.5	4.7	38.3	1.3	13	5.7	29.5	5	107.9

Table 12: Status quo of personal resources WP6

TASK 6.1

Main objective:

Analysis of petrophysical and geomechanical properties of reservoir rock samples and outcrop analogues at different pressure and temperature conditions (**D6.1**):

Status/ Achievements:

- 5 field trips were conducted and a total of 333 samples were taken for petrophysical and rock mechanical investigations; out of which 252 samples are from the Los Humeros area, outcrop analogues and exhumed systems of Las Minas including 70 plugs from 41 core sections of 15 cored wells of the LH geothermal field; and 81 are from the Acoculco area, outcrop analogues and exhumed systems (**D6.1, D6.2 and D6.3**).
- A list of petrophysical and mechanical properties of previous investigations of the two geothermal fields was compiled and made available to all GEMex partners.
- A comprehensive list of planned experiments at the different partner institutions was established and serves to define the workflow of lab experiments.
- The setup of a comprehensive GEMex Outcrop catalogue was started to be able to compare results of petrological, geochemical and petrophysical investigations from different WPs with each other.

- 3 Master thesis were started at TUDA to work on the petrophysical characterization of (i) the basement rocks, (ii) the reservoir andesites and (iii) the reservoir samples of the drill cores.
- Lab experiments both under lab and *in-situ* conditions are ongoing (**D6.1, D6.2 and D6.3).**
- Shallow geophysical field experiments were conducted in Acoculco and Las Minas to determine petrophysical and mechanical properties at a larger scale than the lab scale and thus allow for upscaling.

TASK 6. 2

Main objective:

Create static reservoir models with gridded property values for Los Humeros and Acoculco. Quantify uncertainties in final reservoir model as a result of uncertainties in input parameters.

Status:

In order to create reservoir property models, we will utilize the petrophysical property database, which is being created in Task 6.1 as well as hydraulic properties of fluids, which are derived by data analysis of temperature, pressure and production data from more than 50 CFE wells. Heating up profiles of pressure and temperature data are being investigated to obtain steady state temperature field by following required corrections. This data can then be utilized for calibrating temperature models. Laboratory measurements as well as CFE well data analysis for rock and fluid properties is currently ongoing.

Achievements:

- Temperature, Pressure and Production data received from CFE for more than 50 Los Humeros wells and 2 Acoculco wells, Numerical reservoir simulation report of Los Humeros, 2015.
- Data analysis of pressure and temperature to identify the top and bottom of the feed zones, identifying pressure pivot points (for input towards ***D6.3 and D 6.6***).

TASK 6.3

Main objectives:

- Creating a reliable set of hydraulic fracturing (HF) data under controlled conditions in a laboratory.
- Verification of different numerical hydraulic stimulation design tools using the HF data created.
- Stochastic modeling sequence will be followed for heat transport and fluid flow for both steady-state and transient models for estimating and reducing uncertainty in model predictions for Acoculco.

Status:

- 4 large samples of granodiorite and marble were collected from Las Minas and Pueblo Nuevo Quarry respectively. The field trip for sample collection took place between 17.03.17 – 23.03.17 while the samples arrived in Aachen on 25.01.18. Currently the samples are undergoing cutting and polishing as a preparation for the experiment. Experimental setup is being prepared (preliminary tests on functionality of control software, pumps, data recorder etc.).
- Experimental data from the previous HDR research project, the value of the physical properties and the boundary condition details were distributed to UFZ, GFZ and TNO to start testing/developing their respective simulation codes. UFZ and GFZ are currently testing and developing their codes. TNO plans to start this activity in October 2018.

Achievements:

- The shipment of the large samples of granodiorite and marble for HF experiment arrived in Aachen on 25 January 2018. The shipment was a big hurdle considering the fact that the budget as well as the responsible party for such shipments have not been considered initially during project planning. Managing budget and shipment of samples have taken longer than expected (a delay of more than 6 months).
- Validation of numerical approach for hydraulic-fracture propagation against analytical solutions **(D6.5) – UFZ.** Simulation in progress for the code comparison against experiment of hydraulic-fracture propagation **(D6.5)** in both UFZ and GFZ.

<u>**TASK 6.4**</u>

Main Objectives:

- To characterize adequately the fracture zones using surface and subsurface data. The fracture properties will then be upscaled to obtain an average bulk permeability (Input for **D6.6**)
- Quantify uncertainties for numerical modeling of heat transport and fluid flow by stochastic modelling for both steady state and transient conditions of Los Humeros reservoir model **(D6.3 and D6.6)**
- Assist in permeability characterization and understand stress regimes in the borehole by analysis of the drilling data, such as for example mud loss, in collaboration with other WPs (Contribution towards **D6.6, D8.1 and D8.3)**
- Formulating and testing of plastic yield surface to model brittle-ductile transition at high temperature and high pressure (Contribution towards **D7.2**)

Status:

- Work ongoing to define the thermodynamic conditions of the wells and the reservoir at the feed zones, and the pressure, temperature and enthalpy properties within the well. This provides the base data for the production model (to be performed after the steady state model) which will be used for the calibration of the reservoir model.
- Several wells have data on discharge condition measured at wellhead. We use the pressure and temperature conditions at depth found so far for the feed zones to model the flowing condition. This modeling helps in clarifying the contribution of the feed zones to the well production, and provide the P, T, Enthalpy and steam/brine ratio along all the well profile, down to the well bottom.
- Simulation and validation against analytical solutions of hydraulic-fracture propagation **(D6.3);**
- Development and validation against experimental results on carbonates and basalt formation from literature of a brittle-ductile transition rheological model **(D6.3, D6.6).**

Achievements:

- Development and validation against experimental results on carbonates and basalt formation from literature of a brittle-ductile transition rheological model **(D6.3, D6.6).**

The wellbore model, coupled with the reservoir properties obtained in Task 6.2, provide the thermodynamic description for both the natural (steady state model) an exploitation model (calibrated model) for Los Humeros geothermal prospect, in particular we obtain the P,T, Enthalpy values within the well needed to couple the production data with the reservoir model (**D6.3, D6.6).**

Until now well bore modelling was performed using data from 16 wells only which was received from CFE in July 2017. However, towards end of 2017, data from more than 40 CFE wells have been received and currently these data is being used for integrating in the well bore model.

2.6.1 Task 6.1 Rock, fracture, and reservoir fluid properties

2.6.1.1 Activities

<u>Field trips and sampling campaigns:</u>

- Fieldtrip 1 January 17 (17.-26.01.2017), organised by UNIBA and supported by Mexican partners, 24 samples taken
- Field Trip 2: March 17 (17.-23.03.2017), organised by RWTH and supported by Mexican partners, sample collection for Task 6.1 laboratory measurements and Task 6.3 Hydraulic fracturing measurements. Four large samples for hydraulic fracturing experiments and additionally 10 smaller samples for standard petrophysical measurements were acquired from Las Minas and Pueblo Nuevo Quarry
- Field Trip 3: May/June 17 (24.05.-06.06.2017), organised by TUDA, CNR and Mexican partners
    - a total of 115 samples, summing up to 1140 kg were collected from outcrop analogues in and around both Los Humeros and Acoculco as well as from the exhumed system in Las Minas. All relevant units of both geothermal fields were sampled to acquire a representative sample set for petrophysical characterization.
    - Additionally CFE provided access to the core storage facility at the CFE Los Humeros field camp and we set up a catalogue of all available drill core material of the Los Humeros geothermal wells and photographed them all for the planning of further investigations, sampling and for the general use within the other WPs of GEMex.
    - BGS sampled of rocks in the vicinity of Acoculco, and Los Humeros to provide samples of relatively pristine material for lab experiments. Approximately 20 kg of material was collected, representing the 4 main rocks units of interest (granite, limestone, andesite and ignimbrite).
    - Also sampling approximately 10 kg of altered rocks at Las Minas (link with Task 4.1) to better understand reactions associated with high temperature fluids entering rocks. Specifically targeted were samples showing evidence for igneous-derived, silica-rich fluids interacting with carbonate-rick rocks (marbles and limestones) outside of the skarn zone, and cherts which may have undergone thermal alteration in the marble zone.
    - An extended report on this field trip was compiled by Kristian Bär, Christopher Rochelle and Leandra Weydt and uploaded to the VRE
    - Sample shipment delays have greatly impacted work on these samples, but they are now at the European partners, and their preparation and analysis is ongoing.
- Field Trip 4: Jan/Feb 18 (13.01.-07.02.2017) Joint field trip of WP4 and WP6 TUDa and Uni Bari, supported by Mexican partners (also reported in WP4)

- a total of 148 samples, which were directly cored in the field, were collected from outcrop analogues in and around Los Humeros as well as from the exhumed system in Las Minas and Zacatlan. All relevant units of both geothermal fields were sampled to acquire a representative sample set for petrophysical characterization.
- Additionally CFE permitted extensive sampling of the drill core material at the CFE Los Humeros field camp, which were chosen based on their lithology and the existence of previous investigations published.41 different core sections of the drill cores of 15 wells were sampled and altogether 70 plugs were taken.
- Further sampling of rocks at Las Minas (link with Task 4.1) was performed by BGS to better understand reactions associated with high temperature fluids reacting with rocks.

- Field Trip 5: March 18 (01.-09.03.2018) lead by UNITO and supported by Mexican partners
    - to perform outcrop scale geomechanical and geophysical analysis with shallow geophysical methods (electric tomography and ultrasonic velocity measurements) and for the collection of additional samples for lab analysis to help with the interpretation of the results of the geophysical experiments.
    - In the Acoculco area 6 sites were selected and observed of which 3 sites were selected for the detailed surveys. An overview was given during the project meeting in Bari.
    - For Los Humeros experiments were conducted in the exhumed system of Las Minas only.

Summary Acoculco: a total of 81 samples were taken (see Figure 2 and Figure 3), not yet including the samples of the March 2018 field trip

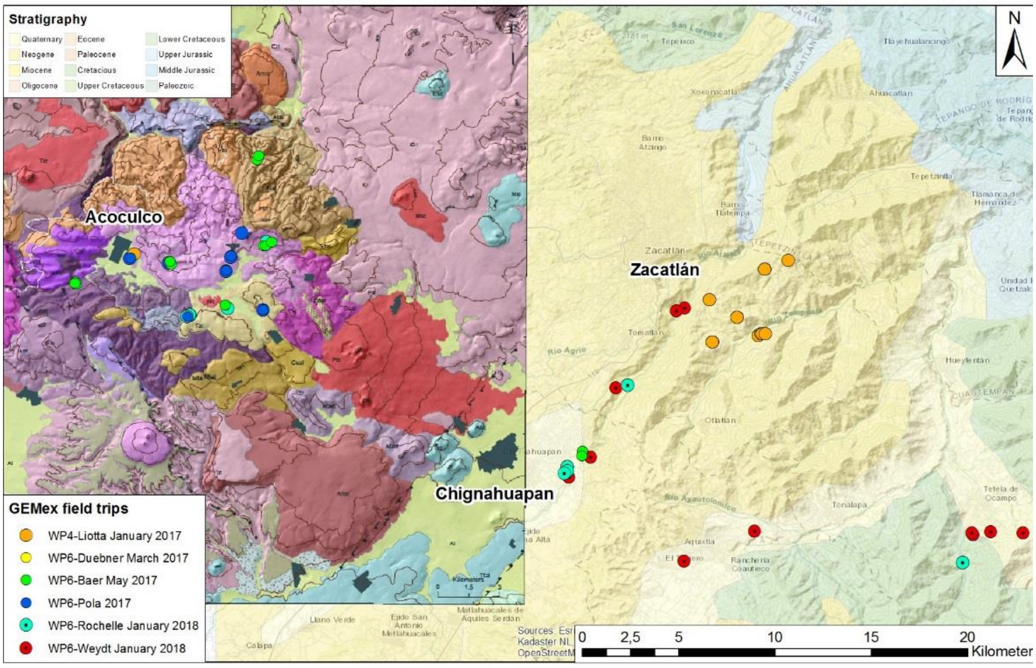

Figure 15: Geological map of the Acoculco area and the exhumed system of Zacatlan (after Avellan et al. 2017) showing all Task 6.1 sampling points of the field trips described in the text, not yet including the samples of the March 2018 field trip.

Period	Age references	Sequences	Units regional model	Number of samples
Holocene - Pleistocene	<0.6 Ma	Extra-caldera volcanism: basaltic to basaltic andesite lava and scoria cones; Alluvium & Apan-Tezontepec monogenetic volcanic field: basaltic scoria cones and alluvium	Unit 4: Extra caldera volcanis & Alluvium	-
Pleistocene	1 to 2 Ma	Late-post caldera: rhyolitic, trachyandesitic and andesitic lavas	Unit 3: Acoculco Caldera Complex	27
Pleistocene - Pliocene	2.1 to 2.6 Ma	Early-post caldera: basaltic and basaltic trachyandesitic lava flows		
	2.6 to 2.7 Ma	Syn-caldera: andesitic ignimbrite covered by lacustrine sediment		
Miocene - Pliocene	10.98 to 3-4 Ma	Pre-caldera: andesitic - dacitic lava and domes	Unit 2: Pre-caldera volcanism	7
	-	Zacatlán basalts: basaltic plateau		
Cretaceous	-	Rocks of Sierra Madre Oriental: limestones, shales, siltstones	Unit 1: Basement	42
Tertiary	-	Batolith: granite		
		not clearly identified yet		5

Figure 16: List of Task 6.1 samples taken in the Acoculco area and in the exhumed system of Zacatlan area, not yet including the samples of the March 2018 field trip. Stratigraphic classification after Avellan et al. (2017).

Summary Los Humeros: a total of 252 samples were taken, not yet including the samples of the March 2018 field trip

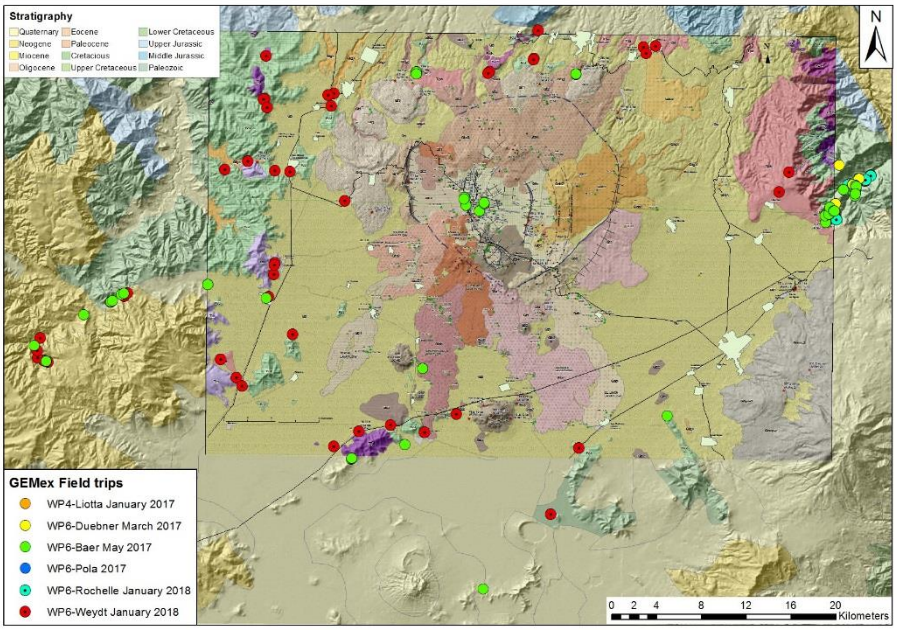

Figure 17: Geological map of the Los Humeros area and the exhumed system of Las Minas (after Carrasco Nunez et al. 2017b) showing all Task 6.1 sampling points of the field trips described in the text, not yet including the samples of the March 2018 field trip.

Era	Age references	Formations and Members	Units regional model	Number of samples
Cenozoic		Olivine basalts	Unit G1: Post-caldera volcanism (< 50 ka)	17
	6,4 ka	Cuicuiltic Member		
	20 ka	Llano Ignimbrite, rhyolitic lava		
	30-40 ka	Tilca Tuff, andesite and scoria cones		
	< 50 ka	Xoxoctic Tuff and El Limon lava		
	< 50 ka	Rhyodacite and andesites lavas		
	100 ka	Zaragoza Ignimbrite	Unit G2: Caldera volcanism (0.5 - 0.1 Ma)	19
	220-350 ka	Faby Tuff and rhyolitic domes		
	460 ka	Xaltipan Ignimbrite		
	470 ka	Pre-caldera rhyolites		
	1.55-5 Ma	Teziutlan lavas	Unit G3: Pre-caldera volcanism	37
		Toba Humeros		
	10.5 Ma	Cuyuaco and Alseseca lavas		
		Granodiorite and syenite	Unit G4: Pre-volcanic basement	148
Mesozoic		Limestone, shale and sandstone		
Paleozoic		Igneous and metamorphic basement		
		not clearly identified yet		31

Figure 18: List of Task 6.1 samples taken in the Los Humeros area and in the exhumed system of Las Minas area, not yet including the samples of the March 2018 field trip. Stratigraphic classification after Carrasco-Nunez et al. (2017b) and Norini et al (2015)

Meetings and Teleconferences:

- First teleconference on Task 6.1 Sample status for laboratory experiments held on the 10.02.2017.
- Second teleconference on Task 6.1 Sample and laboratory investigations status held on the

Petrophysical Investigations:

A list of planned measurements and specific sample requirements per institution was developed and discussed as initial task (Dec. 2016) and is continuously updated serving as a workflow for all ongoing experiments.

Prior to any own measurements a list of measured properties from previous investigations on rock samples or drill cores from the Los Humeros geothermal system published by Contreras et al. (1990), Arrelano et al. (2003), Garcia-Guíterrez and Contreras (2007) and Carrasco-Nunez et al. 2017a) was compiled and extended by additional published measurements on comparably rock types as present in the two geothermal systems.

Finally, after the field trips a list of available samples material and cores was compiled and samples were distributed according to planned measurements. This list is also continuously updated and cross-checked with the GEMex outcrop catalogue.

TUDa performed and ongoing conventional petrophysical analysis: bulk and grain density, porosity, intrinsic permeability, P- and S-wave velocities, thermal conductivity, thermal diffusivity, heat capacity. Most properties are measured both under dry and fully saturated conditions and some samples will be used to measure selected properties at high temperature (up to 170°C) and pressures (up to 60 MPa).

The destructive geomechanical experiments at TUDA are planned after the conventional non-destructive petrophysical characterization of the samples if finished. Unconfined Compressive Strength (UCS), Young's modulus, shear modulus, cohesion, Poisson ratio, tensile strength, shear strength will be measured.

All results will be correlated to the geochemistry, petrology and in cooperation with UniRoma3 with the degree of alteration of the different rock types to facilitate the model parametrization with the help of the available well data.

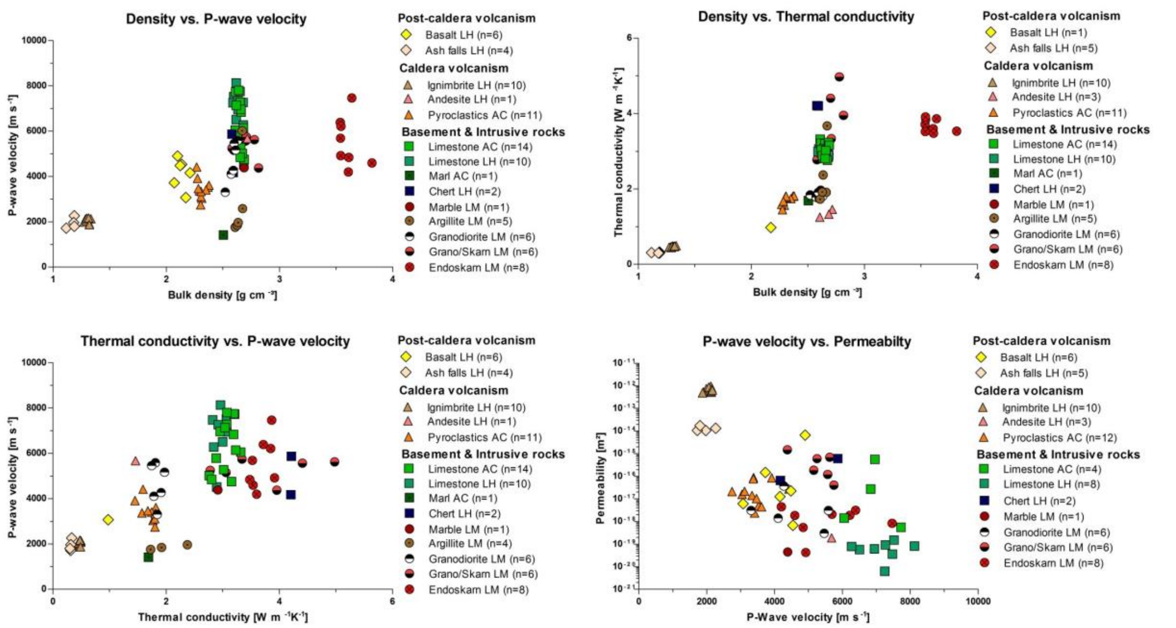

Figure 19: Crossplots of preliminary measurement results of TUDa performed on 52 plugs from the Jan 2017 and 44 plugs from the May/June 2017 field trips (Weydt et al. 2017).

BGS will undertake complimentary geochemical and mineralogical studies to the petrophysical ones of the other partners. These are ongoing, and detailed information about fluid-rock reactions from the lab experiments should be available in the near future.

In terms of borehole samples, BGS has nearly completed analyses of a single sample from H-48. This shows a relatively expected reaction sequence of alteration (formation of quartz, K-feldspar, chlorite and calcite), but also evidence of changing fluid compositions over time (dissolution of some quartz and all the K-feldspar). Interestingly, the most recent precipitates show possible evidence for boiling/vapour separation and oxidation.

In terms of surface precipitates BGS is completing analyses of silica-rich precipitates from surface infrastructure. Evidence for highly porous masses composed of spheres of silica, within which are bands enriched in iron oxides – the latter probably reflecting physical movement of small amounts of corrosion products from inside the well lining can be seen. Associated with some of the iron oxides are sub-micron grains of gold/silver.

GFZ performed conventional petrophysical analysis on additional rock samples from Acoculco: bulk and matrix density, effective porosity, P- and S wave velocities, formation factor, surface conductance, water permeability.

GFZ/TU Delft performed XRF and XRD measurements of all samples of the first field trip January 2017. Additional measurements of the other samples are planned.

GFZ work in progress: special preparation of rock samples for high temperature experiments.

RWTH performed conventional petrophysical measurements of matrix density and bulk density, total porosity, thermal conductivity (dry and saturated), P wave velocity (dry and saturated), specific heat capacity, magnetic susceptibility in the samples collected in January 2017.

Several laboratory tests have been conducted at UNITO on available Mexican samples. Particularly petrophysical properties were measured including: density and porosity measurements, ultrasonic pulse velocity (both P- and S-wave velocities (when possible), electrical resistivity (in dry and saturated conditions). Parallel to this work rock analogue limestone samples, collected in a quarry in North-western Italian Alps, were thermally treated at temperature ranging from 105° to 600°C and subjected to non-destructive and destructive laboratory tests. These tests allowed evaluating the variation in physical and mechanical properties of limestone rocks similar to the Mexican ones as a consequence of temperature. On each sample similar tests to the ones conducted for the Mexican cores have been undertaken with the addition of Uniaxial Compressive Strength tests. All these tests were repeated before and after thermal cycles. These measurements were also interpreted by microscopical observations on thin sections. The increase of crack density with temperature was found to be the main cause of the degradation of physical and mechanical properties. Further processing of these results in comparison with Mexican sample evidence will potentially allow a more complete understanding of the rock behaviour with temperature.

High p/T experiments

Delays in receiving sample shipments have hindered progress with the lab experiments. However, BGS has put on a series of sealed cells where andesitic material is being reacted with synthetic Los Humeros reservoir water at 200°C. The purpose of these tests is to see if similar reactions can be identified to those seen in borehole core samples. Similar experiments will shortly be initiated at 300°C.

GFZ started thermophysical characterization of relevant hydrothermal fluids: The electrical conductivity of NaCl and Na_2SO_4 solutions of different concentrations was measured in dependence of temperature at elevated pressure.

The high p/T set-up for measuring rock properties was redesigned and is currently being tested.

GFZ planned:

- Electrical measurements on salt solutions and their mixtures will be continued

- Fluid-rock interaction experiments will be performed at supercritical conditions to determine the effect of mineral dissolution/precipitation on the electrical properties of the reservoir fluid
- Electrical and hydraulic measurements on fluid saturated rock samples (limestones, volcanic rocks) up to supercritical pT conditions, to determine the effect of fluid-rock interaction on bulk conductivity and permeability.

Shallow geophysical experiments - **Mexican Field work:**

During March 1 to 9, 2018 field works were conducted in the Acoculco and Las Minas areas for shallow geophysical experiments (Electric Resistivity Tomography - ERT) and geomechanical characterization. In the Acoculco area 3 sites were selected for detailed surveys:

- Quarry 6 – 2 electic tomographies, 2 geomechanical surveys, 1 transient station with thermal camera, ultrasonic velocity measurements;
- El campanario – 1 electric tomography, ultrasonic velocity measurements;

Acoculco wells – 2 electrical tomographies.

In Las Minas area 3 sites were selected for detailed surveys:

- Juan Marcos – 1 electric tomography, 1 geomechanical survey, ultrasonic velocity measurements;
- Granados Quarry - 1 electric tomography, 1 geomechanical survey, block sampling;
- Rinconada fault - 1 electric tomography, 1 geomechanical survey, ultrasonic velocity measurements, transient station with thermal camera.

Preliminary results of the ERT surveys have evidenced the presence of electric resistivity anomalies in correspondence of fault zones and of lithological variations (e.g. limestones to andesite).

An example of the combination of the above mentioned studies is reported in were laboratory and field ultrasonic measurements of the Mexican samples are compared to the rock analogue samples.

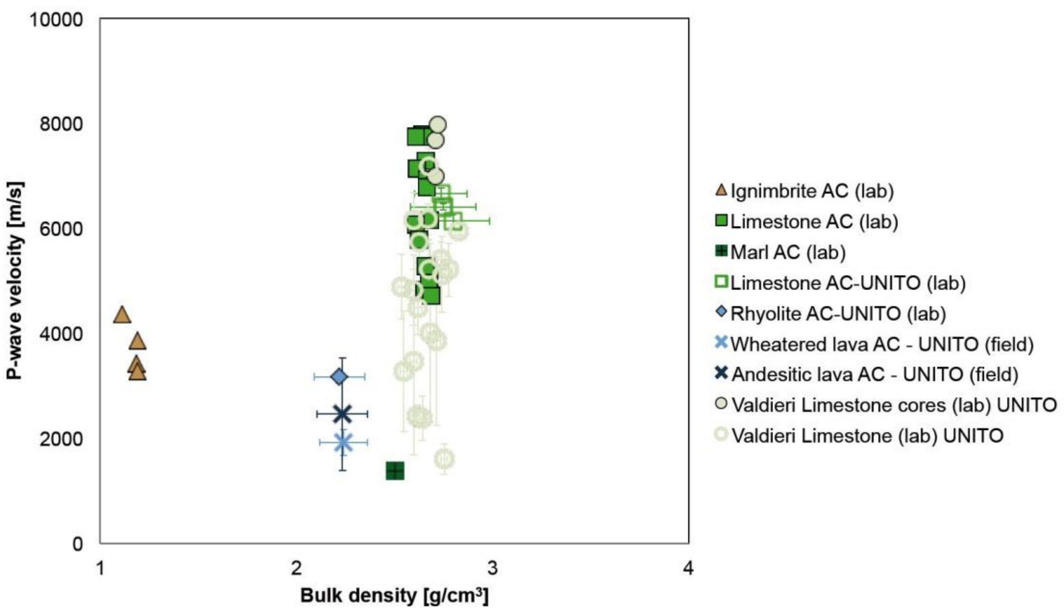

Figure 20: Crossplots of preliminary measurement results of UNITO.

Reservoir fluid properties

Available chemical fluid data for 13 wells at Los Humeros has been screened. Fluid samples date back till 1987 but most data is rather recent, with 7 wells sampled during the years 2016 and 2017.

Overall, liquid sample composition is quite variable showing mixtures of chlorite, carbonate and sulfate salts as well as silica. Total dissolved solid (TDS) content, in contrast, is low and 1.3 g per kg of solute on average and 4 g per kg at maximum. The latter would correspond to an equivalent NaCl concentration of ca. 0.07 mol/l as also reflected by the highest electrical fluid conductivity measured (7 mS/cm at 25°C).

A striking feature of some of the fluid samples (e.g., from well H-58) is an unusually high boron content of up to 3.6 g per kg of solute, presumably present as dissolved borate salts (Bernard et al., 2011).

Regarding the thermophysical liquid phase properties of the fluids, from the low TDS content alone, it is implied that these very closely match with pure water properties at given pressure and temperature conditions, provided that the fluid state is subcritical. Consequently, the respective IAPWS formulations for ordinary water substance (IAPWS R12-08, 2008; IAPWS R15-11, 2011; IAPWS R6-95, 2016) could then be reliably used in reservoir models or for reservoir and plant engineering purposes. This should apply for viscosity, density, sonic velocity, thermal conductivity, and specific heat as indicated in Figure 21 for the aqueous 0.07 M NaCl fluid equivalent mentioned before (e.g., Hoffert et al., 2015). For viscosity, as the physical property in this list most affected by TDS content, the departure from pure water properties should be +1.2 % at most followed by density (+0.24 %), sonic velocity (+0.18 %), thermal conductivity (-0.13 %), and specific heat (-0.31 %), respectively, at 25 °C reference temperature and ambient pressure. Electrical fluid conductivity, in contrast, is significantly affected by TDS content and consequently shows variations between samples ranging from ca. 0.1 to 7 mS/cm at 25 °C.

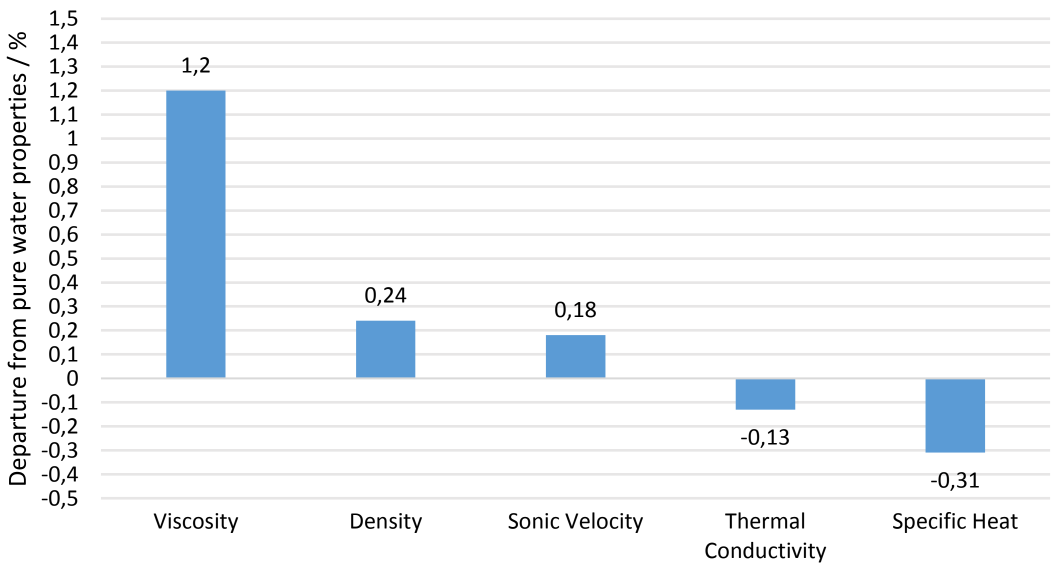

Figure 21: Thermophysical properties of an aqueous 0.07 M NaCl fluid equivalent for Los Humeros geothermal field relative to pure water indicated as percent deviation at 25 °C reference temperature and ambient pressure.

The activities and exchange with other WPs is described in the following table.

WP using preliminary results	Purpose	Partner
WP5	• Measured densities for gravimetric exploration	KIT, TUDa
WP7/8	• Comparison of lab data and petrophysical data from logs and well tests	RWTH, TUDA, CNR, GFZ, GZB
WP4	• Correlate Petrophysics with geochemistry and petrology • TUDa will send offcuts of the drill core material to UniRoma3 for geochemical and alteration analysis. Results will be correlated with petrophysics. • BGS plans to make a comparison between the results of lab experiments (WP6 - when they are completed) and rock samples from Las Minas being analysed in WP4. • BGS plans to compare the lab-generated high temperature fluids with well fluids from WP4.	TUDa, BGS, UniRoma3
WP4	• Use T6.1 samples for fluid inclusion analysis • BGS has selected 2 interesting samples to forward to CNR for fluid inclusion work, and is collecting sufficient metadata to send with these. • Additionally sample material from the drill cores will be selected by TUDa and forwarded to CNR	BGS, TUDa, CNR

Table 13: Interaction of Task 6.1 with other work packages

2.6.1.2 Achievements

- **Milestone M31: Laboratory test samples acquired:** 5 field trips were conducted and a total of 333 samples were taken for petrophysical and rock mechanical investigations; out of which 252 samples are from the Los Humeros area, outcrop analogues and exhumed systems of Las Minas including 70 plugs from 41 core sections of 15 cored wells of the LH geothermal field; and 81 are from the Acoculco area, outcrop analogues and exhumed systems.
- A list of petrophysical and mechanical properties of previous investigations of the two geothermal fields was compiled and made available to all GEMex partners.
- A comprehensive list of planned experiments at the different partner institutions was established and serves to define the workflow of lab experiments
- The setup of a comprehensive GEMex Outcrop catalogue was started to be able to compare results of petrological, geochemical and petrophysical investigations from different WPs with each other.
- 3 Master thesis were started at TUDa to work on the petrophysical characterization of (i) the basement rocks, (ii) the reservoir andesites and (iii) the reservoir samples of the drill cores.
- Lab experiments both under lab and in-situ conditions are ongoing and are on track to being finish to achieve **Milestone M32 : Laboratory tests finished** within the deadline.

- Shallow geophysical field experiments were conducted in Acoculco and Las Minas to determine petrophysical and mechanical properties at a larger scale than the lab scale and thus allow for upscaling.

2.6.2 Task 6.2 Reservoir characterization

Activities (RWTH):

- Literature review for understanding the geology, geophysics and reservoir conditions of Los Humeros and Acoculco.
- Communication (tele-conferences) and discussion with WP 3 towards developing the Los Humeros structural model.
- Import of Geomodeller structural format to RWTH in-house simulation code, SHEMAT suite. Efforts concentrated towards preserving geometry of faults. This structural model is gridded in Shemat Suite and then property modeling is performed.
- Several data requests sent to CFE for well data, geological and geophysical models, reservoir engineering reports, etc.
- Skype meetings with Mexican partners to facilitate collaboration of work for Los Humeros and Acoculco reservoir models.
- Data analysis of pressure and temperature to identify the top and bottom of the feed zones, identifying pressure pivot points (for input towards ***D6.3*** and ***D 6.6***),
- Estimatation of physical (thermodynamic) properties of fluids in Los Humeros (Contribution towards **D6.1 and D6.3**)
- Extraction of information from the available well data to use towards calibration of the reservoir models to be performed in Task **6.4** (Contribution towards **D6.6**)

Activities (CNR):

- Investigation on heating up profile, to identify the possible feed zones
- Investigation on pressure build up during heating, to identify the pivot point and the pressure controlling the feed zones as well as the pressure in the wellbore surrounding
- Wellbore modeling to assess fluid P,T and enthalpy at well bottom

This approach was followed for each well, according to the availability of data.

Activities (UU):

A preliminary regional thermal model for Los Humeros has been developed, building on the regional work that has been done in WP3. The geometry of the model is based on the structure of the volcanological system at regional scale and the conceptual understanding that gives some insight to understand the thermal framework that host the geothermal system. The thermal model uses average lithology for each individual layer and the temperature information from the wells that have been collected and corrected.

Results/ Achievements:

- Request and preliminary analysis of CFE data: Temperature, Pressure and Production data for more than 50 Los Humeros wells and 2 Acoculco wells, Numerical reservoir simulation report of Los Humeros, 2015

- WP3 preliminary Los Humeros models is imported to inhouse Simulation software Shemat Suite and first runs on temperature modeling were performed.
- Well data analysis of temperature data and pressure for identifying characteristics of feed zone is ongoing.

2.6.3 Task 6.3 Model approaches for EGS

Workshop:

- Workshop conducted in RWTH on 20th June 2017 with all partners involved in Task 6.3 for verification of simulation code. Francesco Parisio (UFZ), Hannes Hofmann (GFZ), Peter Fokker (TNO), Stephan Düber (GiB, RWTH), Martin Feinendegen (GiB, RWTH), Paromita Deb (GGE, RWTH) and Yousef Heider (IAM, RWTH) attended the workshop which involved demonstration of the hydraulic fracturing experiment and discussion of the state of the art simulation codes which are used by different institutions for simulation of stimulation approaches. Discussion on upcoming experiments and simulations.

Activities (RWTH):

- Field trip was carried out in March 2017 (also reported in Task 6.1) along with Mexican partners in order to sample rocks for Hydraulic fracturing experiment (field trip: 17.03.17 – 23.03.17, arrival of samples in Aachen: 25.01.18)
  2 large samples of Granodiorite and 2 large samples of Marble each measuring 50 × 50 × 50 cm^3 were sampled from Las Minas and Pueblo Nuevo Quarry which are considered as exhumed systems of Los Humeros and Acoculco.
- Shipment of large sample blocks from Mexico to Germany (**D6.4 and D 6.5)**. The shipment was a big hurdle considering the fact that the budget as well as the responsible party for such shipments have not been considered initially during project planning. Managing budget and shipment of samples have taken longer than expected (a delay of more than 6 months).
- Setup and preparation of HF experiment (preliminary tests on functionality of control software, pumps, data recorder etc.)
- Samples are shipped to Aachen, Germany and handed over to Stone Mansion for cutting and polishing to prepare them for the hydraulic fracturing experiment.
- Experimental data from the previous HDR research project, the value of the physical properties and the boundary condition details were distributed to all Task 6.3 partners to start testing/developing their respective simulation codes.
- First simulation results show high influence of fluid viscosity on fracking process. Research on viscosity of fracturing fluid (glycerol-ink mixture) has shown high temperature dependency. Improvements on experimental setup regarding measurement of fluid viscosity and temperature have been conducted.

Activities (UFZ):

- Literature review of computational methods for hydraulic fracture propagation;
- Simulation and validation against analytical solutions of hydraulic-fracture propagation;
- Simulation and comparison against experimental results on hydraulic-fracture propagation for code comparison **(D6.5).**

Activities (GFZ):

- Simulation and validation of FRACOD2D and PFC2D against analytical solutions of hydraulic-fracture propagation;
- Simulation and comparison of FRACOD2D and PFC2D against experimental results on hydraulic-fracture propagation for code comparison.
- Validation of numerical approach for hydraulic-fracture propagation against analytical solutions ongoing **(D6.5)**

Achievements:

- Validation of numerical approach for hydraulic-fracture propagation against analytical solutions **(D6.5);**

2.6.4 Task 6.4 Model approaches for SHGS

Activities (RWTH, CNR):

- Literature review for understanding of fracture permeability characterization.
- Communication and discussion with other Work Packages (WP 4) for using fracture geometry data collected using scan lines and other geological measurements in order to feed into fracture modeling process.
- Collaborating with other Work Packages to retrieve CFE drilling data. The mud loss data and other drilling data to assist in permeability characterization and understanding stress regimes in the borehole.
- A preliminary rough field model (steady state) was carried out using the data obtained so far in task 6.2 and 6.4, to check the consistency and stability of the model, using the supercritical Equation Of State for water and CO2 developed at CNR-IGG in the framework of DESCRAMBLE project. The model will be refined and updated during the project, and possibly extended down below accounting for the hot rocks intruding the limestones.
- Work ongoing to define the thermodynamic conditions of the wells and the reservoir at the feed zones, and the Pressure, Temperature and Enthalpy properties within the well, providing the base data for the production model (to be performed after the steady state model) used for the calibration of the reservoir model.

Activities (UFZ):

- Literature review on brittle-ductile transition rheology;
- Development of plastic yield surface for brittle-ductile transition at high temperature and high pressure.

Results:

This work, accounting also the input from other tasks, will fulfill the deliverables *"**D6.3** Report on the numerical reservoir model used for the simulation of the Los Humeros reservoir","**D6.6** Report on the calibrated model for the super-hot reservoir at Los Humeros and its calibration against available field data".*

- Starting from the wellhead data during production, and well geometry, we are working towards obtaining a flowing well model that compute the P,T, Enthalpy profile of the well.

- In our case many wells have data on discharge condition measured at well-head, and we used the P,T conditions at depth found so far for the feed zones to model the flowing condition. This modeling help in clarifying the contribution of the feed zones to the well production, and provide the P, T, Entalpy and steam/brine ration along all the well profile, down to the well bottom.
- The wellbore model, coupled with the reservoir properties obtained in task 6.2, provide the thermodynamic description for both the natural (steady state model) an exploitation model (calibrated model) for Los Humeros geothermal prospect, in particular we obtain the P,T, Enthalpy values within the well needed to couple the production data with the reservoir model.
- Simulation and validation against analytical solutions of hydraulic-fracture propagation **(D6.3);**
- Development and validation against experimental results on carbonates and basalt formation from literature of a brittle-ductile transition rheological model **(D6.3, D6.6).**

2.6.5 Publications

Parisio F., Tarokh A., Makhnenko R., Naumov D., Yuan-Miao X., Kolditz O., Nagel T., Experimental characterization and numerical modelling of fracture processes in granite. Journal of the Mechanics and Physics of Solids, under review (2018).

Yoshioka K., Parisio F., Naumov D., Lu R., Kolditz O., Nagel T., Cross-Verification of Discrete and Smeared Numerical Approaches for the Simulation of Hydraulic Fracturing. International Journal of Geomathematics, under review (2018).

Parisio F., Naumov D., Kolditz O., Nagel T., Material forces: an insight into configurational energy. Mechanics Research Communication (2018, Article in press).

Parisio F., Nagel T., Kolditz O., Vinciguerra S., Lithology and dilatancy control the brittle-ductile transition in volcanic areas, Nature Geoscience (2018, submitted).

2.6.6 Dissemination

Weydt, L., Bär, K., Sass, I. (2017): Outcrop Analogue Study to Determine Petrophysical Properties of the Los Humeros and Acoculco Geothermal Systems, Mexico. – Proceedings 5th European Geothermal Workshop, Karlsruhe, 12-13 October 2017.

Weydt, L., Bär, K., Sass, I. (2018): Outcrop analogue study to determine reservoir properties of the Los Humeros and Acoculco geothermal fields, Mexico - Geophysical Research Abstracts Vol. 20, EGU2018-7228, EGU General Assembly 2018.

Kummerow, J., Raab, S., Schüssler, J. (2018). Fluid-rock interactions at near- and supercritical conditions and their effect on physical properties of high-enthalpy hydrothermal systems - Geophysical Research Abstracts Vol. 20, EGU2018-7097, EGU General Assembly 2018.

Montegrossi, G., Deb, P., Clauser, C., Diez, H. and Ramirez, M.A, Modeling of Los Humeros geothermal field: preliminary results, Geophysical Research Abstracts Vol. 20, EGU2018-17600, EGU General Assembly 2018 (Poster Session)

Parisio F., Vinciguerra S., Kolditz O. and Nagel T., The lithological control on the brittle-ductile transition in volcanic areas, EGU General Assembly 2018, Vienna, 8th-13th April 2018, EGU2018-2429

Hutka GA, Hofmann H, Farkas MP, Yoon JS, Zimmermann G, Zang A (2018) Benchmarking of hydro-mechanical coupled models against true-triaxial laboratory hydraulic fracturing experiments. 9th European Geothermal PhD Days, Zürich, Switzerland, 14.-16. March.

Deb et al., Hydraulic-fracturing experiments on a laboratory scale for numerical codes verification, Geophysical Research Abstracts Vol. 20, EGU2018-16136, EGU General Assembly 2018 (Poster Session)

Deb et al., Laboratory fracking experiments for verifying numerical simulation codes, 1354, Hydro-Thermal-Mechanical Modelling in Tight Formations, 80th EAGE Conference, Copenhagen, Denmark, June 2018 (Oral)

Seminar entitled "Enhanced supercritical geothermal systems: toward stimulation design" held at Universidad Politecnica de Catalunya – Instituto de Diagnóstico Ambiental y Estudios del Agua - Consejo Superior de Investigaciones Científicas (UPC-IDAEA-CSIC), March 15th 2018, by Francesco Parisio.

2.6.7 Deviations from the Description of Action

WP6: In course of the amendment, UNITO has shifted budget from "subcontracting" to "direct personnel costs". However during the amendment we forgot to also add the person months which are associated to this. Consequently, UNITO has already used more person months than indicated in the GA for WP6, but they have still enough resources to finish their work in WP6 in the next periods

Task 6.1: Milestone 31 was reached late, only in month 16 instead of month 6: After the first two field trips in January and March 2017 researchers noted that further samples are needed. Therefore additional field trips were organised and a third collection was finished in May 2017, but until July 2017 no shipping company could be found for the transport to Europe (probably because of regulations for export of minerals /fossils).Finally with the help of the Mexican partners, a shipping company was found, but due to administrative issues on the Mexican site, the shipping started end of December 2017; Samples arrived end of January 2018. A fourth field trip was planned and executed in January/February 2018 for final sampling and also sampling the drill cores from the Los Humeros SHGS reservoir, which are very important to be able to compare them to the samples from the outcrop analogue and exhumed systems.

The late reaching of this milestone was one reason for the application for the amendment. After approval of the amendment, the activities of Task 6.1 are on track again and no further delays are anticipated.

2.7 Work Package 7: Concepts for EGS

Lead: TNO
Partners: CNR, CRES, ENEA, GFZ, OGS, RWTH, SSSA, TNO, TUDA, UFZ, UNITO, UU
Duration: month 7-44
Status: started and ongoing

Objectives:

The goal of work package 7 is to develop EGS stimulation techniques capable of achieving sufficiently high and sustainable flow rates in such a way that the environmental effects are minor and acceptable and that the local community is consulted and engaged. This is achieved by developing a numerical model workflow and optimised stimulation scenarios for Acoculco, based on the collected data and models created in the other WPs of GEMex.

Participant number	1	3	5	6	7	8	11	12	15	16	20	23	**Total**
Short name	GFZ	TNO	UU	RWTH	CNR	TUDA	CRES	OGS	ENEA	SSSA	UNITO	UFZ	
PM foreseen in total GEMex	12	15	6	6	1	3	6	4	8	12	8	6	87
PM used	0	4.23	0	0.23	0.3	0	2.2	1.6	2	8.64	1.51	0	20.7

Table 14: Status quo of personal resources WP7

After access to the Acoculco site and relevant data was finally approved in November 2017, a workshop was organised on 26 January 2018, to coordinate and plan work on Acoculco by the WP leads from the EU and Mexican GEMex. The main conclusions from the workshop are that although a geological concept of the area is now more clear, additional observations especially from geophysical studies (WP5) are necessary before realistic simulations and development of stimulations designs can start. If the current planning is realised, most data should be available April 2019. Especially at the Mexican side, planning is crucial since they will provide the geophones for geophysical acquisition to be used in Acoculco.

Only little work has been done in tasks 7.1 and 7.2 as both tasks officially start in M19. For task 7.3 a literature and data review has been carried out, which is limited because no seismic data are available yet for the Acoculco site. Considerable achievements have been realised in task 7.4 with the design of a questionnaire to be used in a local perception study.

No exploitable results have been achieved so far.

No deviations from the Description of Action have to be reported.

2.7.1 Task 7.1 Integrated reservoir model

Not started yet.

2.7.2 Task 7.2 Stimulation Design

Not started yet.

2.7.3 Task 7.3 Induced seismicity and environmental hazards

ENEA has collected data on the stratigraphy and seismicity of Acoculco and Los Humeros. Stratigraphic reconstruction based on acquired wells stratigraphy of the main lithological units in Acoculco and Los Humeros have been completed. A review report on induced seismicity is in progress.

Assuming a generic EGS system, because of lack of specific-case data (waiting for Acoculco data), OGS is performing a review study on the control procedures applied for a number of some well-known cases. Until now OGS has performed a literature review on seismic hazard monitoring for EGS sites with special attention to the following field cases: Fenton Hill (New Mexico, USA); Rosemanowes (Cornwall, UK); Hijiori (Japan); Soultz (France); Cooper Basin (Australia); Basel (Switzerland); Landau (Germany); Berlín (El Salvador). This analysis is focused primarily on seismic monitoring, correlation between seismicity and exploitation activity, and alert protocols. Existing protocols for induced micro-seismicity monitoring that can be suitable for the EGS systems in the study area have been reviewed and discussed. The same results and methodologies obtained for T7.3 will also be used for the purposes of WP 8.

2.7.4 Task 7.4 Public engagement

Objectives:
The task aims to define a conceptual and practical model for implementing public engagement strategy to support and improve the local acceptance of the development of geothermal energy activities (enhanced geothermal system (EGS) and super-hot resources (SHSG)).

The design of a conceptual model requires the identification of suitable stakeholders that can assume an active and passive role in the development of geothermal energy projects. Then, a quali-quantitative investigation is carried out on different stakeholders to discover their interpretations and perspectives on geothermal energy development issues. Questionnaires and unstructured interviews will be submitted to citizens, companies, public authorities and local communities both in Mexico, Europe and several developing countries. Based on the results of these activities, a framework is being built to integrate public authorities' and private companies efforts in fostering sustainable energy transition by taking into account local communities' ordinary life and socio-economic needs and the perception of companies' behaviors (social responsibility) related to energy projects among the wider group of final energy consumer.

Activities:
(M1-M6) Preparatory action to fine tune the focus of the activities foreseen in the task 7.4:

- Cooperation with Mexican partners for planning activities regarding social acceptance and public engagement strategies (emails, conference calls and attendance at *1st Simposio Ambiental, Economico y Social de sistemas geotermicos mejorados y supercalientes in Morelia (Mexico) February 26, 2017*).
- Cooperation with European partners for planning activities regarding social acceptance and public engagement strategies (emails, conference calls, physical meeting in Pisa 8 Feb 2017.

(M1-M18) Identification of stakeholders for carrying out interviews and questionnaire

- Collection of information to design a stakeholders' map.
- Collection of information to assess the feasibility of in-field activities through a strong cooperation with Mexican colleagues:
  - Arrangement of the seminar "Geothermal energy and society: social acceptance and public engagement in geothermal energy developments" (16th of April 2018) in Mexico with CFE and Mexican social-economic-environment research team.
  - Arrangement of fieldwork in the 4 local communities (ejidos) of interest for the GEMEX in order to carry out interviews with some representatives of communities in April 2018.
  - Collection of preliminary sociodemographic data related to the 4 local communities (ejidos) that will be involved in the 7.4 task fieldwork in April 2018.

(M5-M15) Literature review on public engagement for the development of geothermal projects

- Review of practices from the side of project developers and operators in order to achieve social acceptance of geothermal power plant projects.
- Measurement methods of socioeconomic impacts of renewable energy projects.
- Review of current literature about public authorities' activities to engage population and stakeholders in the renewable energy projects.
- The relationship between consumers and companies in the development of renewable energy projects.

(M15-M18) Design of questionnaire and interview protocol and collection of data

- Design and launch of the questionnaire survey to investigate consumer's loyalty toward energy utilities involved in the development of geothermal energy projects. The survey has been carried out in Mexico, Brasil, China, Russia, South Africa, and India by collecting around 300 questionnaires for each country.
- Design of a short questionnaire to investigate energy use and knowledge in local communities located in Acoculco area. The questionnaire, with the support of Mexican colleagues, is going to launch in July 2018.

(M1-M18) Internal communication activities

- 5 teleconferences were held with 7.4 task members and Mexican colleagues during the reporting period:

2.7.5 Dissemination and communication activities

- Submission of the abstract Eleonora Annunziata, Michele Contini, Fernando Diaz, Spyros Karytsas, Adele Manzella, Dario Padovan and Alessandro Sciullo "Public engagement strategy: a conceptual model for enhancing the development of geothermal energy" to the International Conference "Breaking the Rules! Energy Transitions as Social Innovations"

2.7.6 Deviations from the Description of Action

No deviation in the reporting period.

2.8 Work Package 8: Concepts for Superhot

Lead: GFZ
Partners: CRES, ENEA, GFZ, HBO, IFE, ISOR, OGS, RWTH, TNO, UFZ, UU
Duration: month 1-44
Status: started and ongoing

Objectives:

In WP8 we aim to develop and verify concepts and technologies to access and exploit super-hot reservoirs (> 300°C, including conditions above the critical point of water in the reservoir) on the basis of the work and data derived in SP1 and SP2 combined with additional information provided by the operating site in Los Humeros. Main objectives are:

- To integrate the results obtained from the technical work packages 3-6 and use them in various model approachs in order to predict the reservoir properties
- To prepare a list of material suitable for installation in super-hot conditions
- To prepare a best-practice guide for drilling and completion in super-hot setting
- To to give recommendations for a thermal loop design
- To provide propose a montoring systems in order to avoid or mitigate potential threads for the environment

Participant number	1	2	3	5	6	10	11	12	15	19	23	**Total**
Short name	GFZ	ISOR	TNO	UU	RWTH	IFE	CRES	OGS	ENEA	HBO	UFZ	
PM foreseen in total GEMex	15	20	6	6	6	2	6	3	8	10	6	331.5
PM used	0	3.2	1.1	0	0	0	1	0.5	0	5	6	16.8

Table 15: Status quo of personal resources WP8

In Task 8.1 a detailed plan for the modelling of the reservoir has been set-up. The task is strongly depending on the input from the other work packages, namely WP 3 for the static geological model and WP6 for the shared simulation model in terms of a gridded subsurface model with geological properties assigned. Consequently only a few activities have yet been conducted. Once the gridded reservoir model is available, the task partners agreed to conduct three different types of simulation: 2D-2phase calculations with TOUGH, modeling of continuum damage and fracture propagation, and semi-analytical coupled modelling. Based on the results from the simulations, recommendations for drilling and sustainable reservoir exploitation will be established.

In Task 8.2 intensive discussion with the Mexican partners and the operator in Los Humeros (CFE) concerning the material tests have been conducted. The preparation of the on-site test is ongoing, material have already been selected and a workflow for the analysis of the tested material has been set-up.

In Task 8.3 a review of the specific drilling and completion problems in Los Humeros has been conducted. In parallel, experience from other super-hot sites is collected and evaluated. Detailed summary and description of results will serve as a draft drilling concept for SHGS as being described in D8.3 for the design of well completion.

No deviations from the Description of Action have to be reported.

2.8.1 Task 8.1 Prediction of reservoir properties

Work package 8.1 addresses numerical modelling of superhot geothermal systems (SHGS). It targets the deep subsurface below already existing wells of Los Humeros.

A workshop was held 23/5/2017 in Potsdam to streamline the activities in this work package and to discuss mutual dependencies. Delegates were present from GFZ, UFZ, TNO/UU and RWTH.

Based on the gridded model, dynamic simulations will be performed in different ways. We envisage

- 2D-2phase calculations with TOUGH (GFZ). GFZ will collect and combine as many data as possible (hydraulic, chemical, thermal, mechanical) as a base for the models. A master student will join as from April on to start this data collection.
- Brittle-ductile transition in superhot geothermal systems and modeling of continuum damage and fracture propagation (UFZ). UFZ will set up a constitutive model for the brittle-ductile transition and use it as the base for fracture propagation analyses in high temperature and pressure conditions.
- Semi-analytical coupled modeling (TNO/UU). A first assessment has been made of available coupled semi-analytical approaches. Here, the approach of Atefi-Monfared et al. seems to be promising: a 1D approximation of the geomechanical response, which might be feasible for complicated constitutive models, calibrated by 3D responses for simple constitutive models.

Main activities

- Literature review of brittle-ductile transition in volcanic areas and systems;
- Numerical simulations with a brittle-ductile transition model to understand fracture propagation at high pressure and high temperature conditions.
- Thermo-hydro-mechanical simulations of hydraulic stimulations with inelastic constitutive model.

Main results to be included in Deliverables D8.1 and D8.4

- Development of a rheological model;
- Analyses of localization and failure in high temperature and high pressure conditions;
- Correlation between seismicity and rheology in volcanic areas;
- Assessment of brittle-ductile transition depth in basaltic and carbonatic volcanic;

2.8.2 Task 8.2 Materials for installation in super-hot systems

During the Kick-off Meeting (KoM) of the GEMex project in Morelia it was proposed that ÍSOR would run a workshop in connection to Task 8.2 on corrosion and scaling. On 6th – 10th March 2017 the workshop was held in the offices of the Los Humeros geothermal field in Mexico. Participants were GEMex partners, over 25 attendees, mostly from Comisión Federal de Electricidad (CFE), engineering, chemical and operational exerts as well as partners from Universidad Nacional Autónoma de México (UNAM), Universidad Michoacana de San Nicolás de Hidalgo (UMSNH), Instituto Nacional de Electricidad y Energías Limpias (INEEL), Iceland GeoSurvey (ÍSOR) and the German Research Centre for Geosciences (GFZ).

After the workshop CFE asked for guidelines for corrosion testing in flowing high-temperature geothermal well. ÍSOR along with UNAM have worked in cooperation with CFE towards providing such guidelines. Materials that will be tested have been selected and gathered from various sources and are ready to be cut into samples once the test setup has been finalized. Preparation of the on-site material test is ongoing.

Additionally, UFZ has worked on numerical modeling approaches for metal corrosion. UFZ has achieved a review of constitutive model of plasticity and damage for strength of metals as a function of corrosion.

2.8.3 Task 8.3 Drilling and completion

GFZ, OGS, BRGM and international partners compiled the worldwide drilling activities of superhot geothermal systems (Reinsch et al 2017). The work outlines the challenges and potential opportunities that these systems provide for international collaboration to ultimately utilize supercritical geothermal systems as a geothermal energy resource.

HBO has done a more detailed review of past drilling escapades in other super-hot locations worldwide, investigated conditions of LHGF together with completion and drilling techniques used and kick-started laboratory experiments on improvements of conventional cement blends in super-hot locations as well as FEM modelling.

HBO conducted an onsite meeting February 19-20 2018 in Morelia, Michoacán (Mexico) with drilling and completion experts, geologists and geochemists from Comisión Federal de Electricidad (CFE) in Morelia and Los Humeros. Between 21st and 23rd of February 2018, field trips to Los Humeros and Acoculco geothermal fields were organised in order to investigate problems up close. After very successful meetings and discussions with CFE detailed and proprietary drilling related data had been requested for several, selected wells including:

- daily drilling reports including detailed drilling parameters and logging data such as Leak Off Test (LOT) etc.
- cement composition
- properties of drilling fluid,
- summary of challenges concerning drilling and well completion.

CRES has investigated and reported experience from practices adopted in other wells which encountered superhot temperatures (e.g. Nisyros 1, Greece).

Detailed summary and description of results will serve as a draft drilling concept for SHGS as being described in D8.3 for the design of well completion.

2.8.4 Task 8.4 Thermal loop design and performance monitoring

Allthough Task 8.4 has not yet officially started, some activities have already been carried out be the partners in order to facilitate a smooth start of the task.

CRES carried out a literature review on surface expoitation and monitoring schemes. ENEA focused on description of a monitoring system for soil mobility of elements during geothermal exploitation of superhot systems. Geothermal areas are characterised by high levels of Potentially Harmful Elements (PHE). In particular, some heavy metals as: As, Cu Pb, and Hg in some conditions, evidence a higher mobility respect the "pedogenic" elements, promoted by the low pH and by the soil microorganisms adapted to survive in such environments. These environmental aspects are studied reviewing suitable tools to monitor PHE concentration levels and distribution pattern. This activity is necessary to manage actions to reduce both pollution and to reduce the population risk. Until now ENEA focused mainly on carrying a critical review on the mobility of trace elements in soils, focused on geothermal soils with the purpose to give a picture of the state of art on this subject and to suggest innovative and "rapid" chemical approach to test pollutant mobility. For the next reporting periods, our aim is to compare some mobility tests in soils from Mexico geothermal areas with soils collected in a different geothermal areas as the Flegran Field, with the aim to suggest a innovative chemical approach methods to test trace elements mobility in such environment.

2.8.5 Publications

Reinsch, T., Dobson, P., Asanuma, H., Huenges, E., Poletto, F., Sanjuan, B., (2017): Utilizing supercritical geothermal systems: a review of past ventures and ongoing research activities. - Geothermal Energy, 5, 16.

Parisio F., Nagel T., Kolditz O., Vinciguerra S., Lithology and dilatancy control the brittle-ductile transition in volcanic areas, Nature Geoscience (2018, submitted)

2.8.6 Dissemination activities (talks, posters, workshops)

Parisio, F., "Enhanced supercritical geothermal systems: toward stimulation design", seminar held at Universidad Politecnica de Catalunya – Instituto de Diagnóstico Ambiental y Estudios del Agua - Consejo Superior de Investigaciones Científicas (UPC-IDAEA-CSIC), March 15th 2018

Parisio F., Vinciguerra S., Kolditz O. and Nagel T., "The lithological control on the brittle-ductile transition in volcanic areas", European Geosciences Union General Assembly 2018, Vienna (Austria), 8-13 April 2018

2.9 Work Package 9: Ethics

Lead: GFZ
Duration: month 1-44
Status: started and ongoing

Objectives:

This work package sets out the 'ethics requirements' that the project must comply with. There is only one deliverable which must provide details on the material which will be imported to/exported from EU and provide the adequate authorizations.

Status:

No person months are associated with this work package. The coordinator takes care of the compliance with the ethic requirements.

Up to now import and export to/from Mexico included mainly two things:

- Equipment or scientific measurements: all equipment which is imported to Mexico and was / will also be exported. Hence, the project partners acquired a permission for temporary import of scientific equipment which was checked by the Mexican customs.
- Export of samples of rocks, fluids and gas: all samples were of scientific value only and had no significant content of fossils or minerals. Consequently they neither represent a commercial value, nor are they of historical value to the Mexican people. Again, the export of samples was always checked and authorized by the Mexican customs.

3 Impact

The Impact as detailed in section 2.1 of the DoA is still relevant. In addition to the DoA, we can report the following impact of the project after the first reporting period subdivided into a “scientific”, and “technological” impact:

Scientific

- Peer reviewed publications: 3 published, 4 submitted
- Presentation on conferences: 22
- Master thesis:1
- Transfer of knowledge:
  - Through collaboration within GEMex, we strengthen the transfer of knowledge between the 31 involved Mexican and European partners
  - with strong links to other H2020 projects (GeoWell, DESTRESS, SURE, DEEPEGS, DESCRAMBLE and IMAGE) as well as recent the Mexican project CEMIE-Geo, we additionally ensure a transfer of knowlegde gained in other H2020 projects to the European and Mexican research community

Technology

- Patent application on a tracer for superhot resources (WP4)

4 Deviations from Annex 1 (if applicable)

4.1 Tasks

Task 2.4: RWTH has used 0.24 PM for Dissemination although this was not foreseen in the GA. Paromita Deb from RWTH took part in the EU-MX dialogue on Energy and gave an invited presentation on GEMex on behalf of the coordinator.

Tasks 3.3: The analogue modelling laboratory of CNR-IDPA has rescheduled its activity with the aim of a better integration among the three analogue modelling laboratories involved in the Task 3.3 (CNR-IGG, CNR-IDPA and UROMATRE) and an efficient use of their instrumental resources. For this reason, the laser scanner mentioned in the GA will not be acquired, and the budget will be used for other equipment and eligible costs. Nonetheless, the duties, deliverables and schedule of the laboratory will not be affected by this deviation, as the analysis will be conducted with alternative techniques (digital photogrammetry) in collaboration with the other two laboratories.

Task 4.2: Isotopic analyses on the altered core-samples of Los Humeros geothermal wells are delayed as these samples have only recently arrived in Europe and they will be used for other analyses before they can be made available for isotopic analyses. If the samples are sent to the CNR within 3-4 months the isotopic analyses will be carried out within the project extension period.

Only one sample of the mafic dikes collected by CNR in the basement surrounding the Los Humeros caldera is fresh enough to allow radiometric dating. The sample have been hand-crushed and sieved, and the groundmass (fraction 250÷355 µm) has been separated using magnetic methods followed by handpicking under a binocular microscope. The radiometric analysis is in delay as the 40Ar-39Ar laboratory at CNR-IGG is currently under maintenance. The analysis will be scheduled as soon as the laboratory equipment will become fully operational and the analysis will be carried out within the project extension period.

Task 4.3, Subtask 4.3.2: At the beginning stage of the project, the activities were delayed due to internal issues on the Mexican side (multiple changes of task leaders, financing issues, etc.). Also, during the sampling campaign (carried out by IGG-CNR) on 2017 in LHGS, customs authority (Guadalajara airport) retained all scientific equipment shipped from Italy, obstructing the import processing and the regular schedule of the planned work. The process to recover the equipment was extremely delayed due to lack of communication between Mexican Airport Customs and Mexican partner involved. Now, the equipment seems to be missed and its searching process represents a very difficult challenge. Even if the equipment is still retained by the Mexican customs, the planned activity for 2017 was complete and is ongoing for 2018.

The approximate progress of the BRGM contribution in task 4.3 until now is close to 10%. Relative to the planned schedule, the BRGM activities have been slowed down, given that the campaign of fluid sampling has been delayed from 6 to 7 months, but this deviation is still acceptable.

Task 5.2: Subtask 5.2.1 c) There is no activity planed so far concerning the DAS acquisition method. The reason for this is that the DAS acquisition was foreseen for the site in Acoculco in the assumption that a new well would be drilled. A DAS installation would only make sense if the cable would be deployed before/during the casing of the borehole because the measurement requires a good coupling of the cable to the drilled rock. This was not correctly communicated between the two consortia and it came to our attention only after the signature of the GA, that there will be no new drilling in Acoculco. Consequently, we do not see a possibility for DAS installation during the lifetime of the project.

The completion of Milestone 28 will be reached in M20 instead of M12: The deployment of seismic stations in Los Humeros was already finished in M13 (only two stations were added in M18). However we had no permission to install instruments in Acoculco until December 2017. Hence, all European stations have been installed in Los Humeros and it was agreed that the Mexican teams will deploy their newly acquired stations in Acoculco. The Mexican stations have only arrived in Perote in March and deployment is starting. 16 Mexican stations will be deployed by the Mexican team and data sharing with the European team as with the Los Humeros dataset is foreseen.

Subtask 5.2.2 d) Attenuation: Even if foreseen in 5.2.2d, at the moment no borehole seismic data (VSP) are available, therefore, not usable for seismic interferometry with body waves at depth from active sources (5.2.2c) and attenuation analysis (5.2.2d) as initially expected.

Task 5.3: The completion of Milestone 29 will be reached in M20 instead of M12: A second fieldwork in Los Humeros and Acoculco is scheduled from 12.4.2018 to 16.5.2018. This will include the final acquisition of the necessary “other” geophysical data. The deliverable will be reached in month 32.

WP6: In course of the amendment, UNITO has shifted budget from “subcontracting” to “direct personnel costs”. However during the amendment we forgot to also add the person months which were associated to the subcontracting. Consequently, UNITO has already used more person months than indicated in the GA for WP6, but they have still enough resources to finish their work in WP6 in the next periods.

Task 6.1: Milestone 31 was reached late, only in month 16 instead of month 6: After the first two field trips in January and March 2017 researchers noted that further samples are needed. Therefore additional field trips were organised and a third collection was finished in May 2017, but until July 2017 no shipping company could be found for the transport to Europe (probably because of regulations for export of minerals /fossils).Finally with the help of the Mexican partners, a shipping company was found, but due to administrative issues on the Mexican site, the shipping started end of December 2017; Samples arrived end of January 2018. A fourth field trip was planned and executed in January/February 2018 for final sampling and also sampling the drill cores from the Los Humeros SHGS reservoir, which are very important to be able to compare them to the samples from the outcrop analogue and exhumed systems.

The late reaching of this milestone was one reason for the application for the amendment. After approval of the amendment, the activities of Task 6.1 are on track again and no further delays are anticipated.

4.2 Use of resources

The expenditure of resources, person months and budget, is overall in line with the foreseen amounts. However, there have been some changes, which are explained in the table below if the costs were higher than 3000€. More details can be found in the financial statements of each partner.

Partner	Not planned resources	Explanations/ Change
All partners	11,251.68 €	Additional costs for EMDESK license subscription for setting up an internal communication reporting tool within, estimated to 11,251.68 € for the entire project duration. Each project partner therefore has to pay additional 468.82 € for the license. Before signing the contract for using EMDESK on GEMex, the coordinator had contacted the project officer for approval of these additional costs, which were approved upon.
GFZ/RWTH	3,116.15 €	A dissemination activity was carried out as a result of request from the EU Delegation, Mexico in context to the EU-Mexico Energy Dialogue. Budget from GFZ should be transferred to RWTH for this travel.
GFZ	9,081.00 €	9,081.00 € had to be paid for catering during the joint project meeting with the Mexican project in Iceland, Akureyri. The coordinator has accounted for this budget because some of the personnel costs could be saved due to GFZ providing in-kind contributions to the project.
GFZ	5,232.13 €	Costs for transport of large blocks for the hydraulic fracturing tests were unexpectedly high and GFZ had to cover those costs to ensure the feasibility of the hydraulic fracturing test within Task 6.3. GFZ provided the budget. Costs for kick-off meeting of GFZ were lower than expected, such that the planned ressources could be used for the sample transport.
GFZ	5,180.77 €	3 scientists, Workshop Los Humeros (Mexico) March 2017: The workshop was necessary to increase the communication with the Mexican partners but especially with CFE and gain their trust in the project. Also the Material test to be conducted within Task 8.2 was prepared and close contact between the GEMex researchers and CFE staff established. Budget is shifted from the personnel costs because GFZ provided personnel in-kind to the project.

GFZ	5,302.51 €	3 scientists, workshop and management meeting, June 2017, Morelia (Mexico): Extended Executive Board meeting and workshop together with Mexican WP-leaders and CFE staff to identify common interests between the project and CFE and to clarify the projects objectives and the necessary steps to reach those. Budget is shifted from the personnel costs because GFZ provided personnel in-kind to the project.

Table 16: Changes in the use of resources (compared to the Grant Agreement). Only costs above 3000 € are listed. More details can be found in the financial statements of each partner.

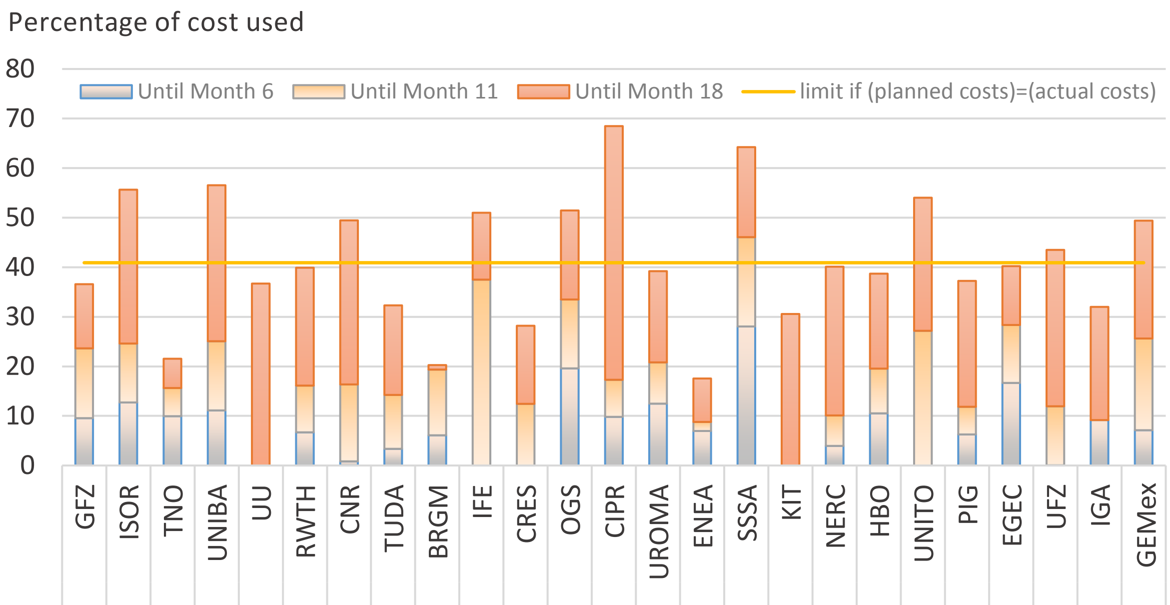

Figure 22: Percentage of budget used during the first period of GEMex by partner. The horizontal line shows the expected costs if the budget use would be exactly proportional to the project runtime (18 months).

Due to administrative reasons, IGA has not submitted a financial statement for this reporting period. However, they have internally reported their use of ressources, which is fully in line with the foreseen budget.

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