United Nations Educational, Scientific and Cultural Organization

Report year: **2017**

Annual Report* of IGCP Project No. 641

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Send to UNESCO and IUGS
ml.faber@unesco.org
iugs.beijing@gmail.com
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A LIST OF PUBLICATIONS HAS TO BE ADDED AS AN ANNEX.

***REMINDER: IF THIS IS THE FINAL YEAR OF YOUR PROJECT, PLEASE SUBMIT A REVIEW ARTICLE ABOUT YOUR PROJECT TO THE IUGS JOURNAL '*EPISODES*'.**

The scientific information in this report will further be used for publication on the IGCP website hosted at UNESCO (please feel free to attach any additional information you may consider relevant to the assessment of your project).

IGCP project short title: Deformation and fissuring caused by exploitation of subsurface fluids (M3EF3)

Duration: 4 years

Please tick this box if the report is for a Project on extended term (OET): ☐

Project leader(s):

1. Name: Dora Celia Carreon Freyre
Address: Bd. Juriquilla 3001. Col. Juriquilla, Queretaro. Qro. 76230 MEXICO
Tel.:+52 442 238 1104 ext 112
Fax: +52 442 238 1101
Email: freyre@geociencias.unam.mx
2. Name: Devin Galloway
Address: Indiana Water Science Center, 5957 Lakeside Blvd., Indianapolis, IN 46278, USA.
Tel.: +1 916-801-2040
Fax: +1 317-290-3313
Email: dlgallow@usgs.gov
3. Name: Pietro Teatini
Address: Dept. of Civil, Environmental and Architectural Engineering, Via Trieste, 63, 35121 Padova, ITALY

Tel.:+39 049 8271330
Fax: +39 104 8271333
Email: pietro.teatini@dmsa.unipd.it

4. Name: Shujun-Ye
Address: Nanjing University. Member UNESCO WGLS. Dept. of Hydrosciences, Nanjing 210023, P. R. CHINA.
Tel.: +86 25 89684150
Fax: +86 25 83686016
Email: sjye@nju.edu.cn

Project Secretary:

Name: Carlos Hernandez
Address: Bd. Juriquilla 3001. Col. Juriquilla, Queretaro. Qro. 76230 MEXICO
Tel.:+52 442 238 1104 ext 174
Fax: +52 442 238 1101
Email: carlosh@geociencias.unam.mx

Date of submission of report: 1st December, 2017

Signature of project leader(s):

Dora Carreon-Freyre

Devin Galloway

Pietro Teatini

Shujun Ye

ANNEXES

ANNEX No. 1. Complementary Information

2. Summary of major past achievements of the project

IGCP Project 641 (M3EF3) aims to better understand the mechanisms that cause the formation of "ground fracturing", as a response to the changes in the stress state in the subsoil by monitoring the worldwide development of "ground fracturing" and by bringing together the international experts to discuss and to develop new scientific models for ground fracturing formation and growth. The occurrence of ground fractures due to extraction of fluids from the subsurface (principally groundwater, oil and gas) has previously been observed in numerous semiarid sedimentary basins worldwide.

- An international network of about 50 researchers from 12 countries established;
- A M3EF3 project web-page has been developed within ResearchGate (https://www.researchgate.net/project/Mechanisms-Monitoring-and-Modeling-Earth-Fissure-generation-and-Fault-activation-due-to-subsurface-Fluid-exploitation-M3EF3) with about 30 participants;
- Update of the project website;
- Publications in international journals;
- Two sessions (NH014, H087) co-organized at AGU Fall Meeting 2016; one special session organized at the Reunión Anual de la Unión Geofísica Mexicana (RAUGM), 2–3 November 2016 in Puerto Vallarta, Mexico
- One course (1-day classroom, and 1-day field trip) on the M3EF3 topics held within the Reunión Anual de la Unión Geofísica Mexicana (RAUGM), 2–3 November 2016 in Puerto Vallarta, Mexico with approx 30 participants, mainly MsC and PhD students

3. Achievements of the project this year only

3.1. General scientific achievements

Scientific achievements in each of the 3 main topics of the project can be summarized as follows:

- *Mechanisms*: The main 3-4 mechanisms responsible for ground rupture development in subsiding basins were defined. Appropriate new material was been added to the project website. A theoretical modelling study was begun and the ongoing study seeks to understand from the quantitative point of view the main drivers/conditions causing earth fissure development (preliminary results will be presented in December 2017 at MODSIM2017 international conference). Specific investigations were done in Spain (University of Alicante) to understand the mechanisms responsible for earth fissuring in the Guadalentin Valley.

- Monitoring: Specific in-situ and remote-sensing methodologies were developed, tested and established. In particular, fiber-optics horizontal extensometers were established in Wuxi (China); advanced FFT analyses of InSAR-based displacement maps and time series were applied to Mexico City; novel 3D reconstruction of fissure geometries from drone acquisitions were developed in Spain (University of Alicante) and tested on specific, ground-mapped fissures in Arizona.
A first map of ground fractures was developed for Mexico City. A novel approach of evaluating and mapping geologic hazards related to ground fracturing was previously developed and applied to the Iztapalapa Delegation, in Mexico City.

The Mexico City fracture map is a part of the National Atlas of Risks in Mexico and a manuscript discussing the distribution of the fractures is in preparation. This map shows that large displacements in ground fractures are related to the land subsidence in Mexico City, one of the major cities affected by these phenomena.

A first world map of the ground ruptures occurrence has been released and published on the project website at *http://www.igcp641.org/?page_id=45*.

- Modelling: To understand the geomechanical processes caused by groundwater pumping in a sedimentary basin we developed an integrative analysis using 3D numerical models with an accurate geological framework. The heterogeneous distribution of the geomechanical properties and the differential deformation and stress field in a subsiding basin is a complex issue that has not been addressed in detail in the literature. A manuscript with these results was submitted recently (Ochoa et al., submitted). Specific 3D numerical models using Finite Elements and Interface Elements were developed and applied for two sites, Wuxi, China, and Queretaro, Mexico. A methodological approach was proposed for the general prediction of fissure occurrence: The usual problem of lack of hydrogeologic information is overcome by nesting 3D regional and local groundwater flow and geomechanical models. The regional models, properly calibrated using observations from regional piezometric and subsidence monitoring networks, allow characterization of aquifer-system properties, and identification of zones prone to fissure development (stress analyses). The local models allow quantification of the geometric properties (length, depth, sliding, opening) of the fissures. This new methodology allows scientists (for the first time) to account for the development and motion on fissures as features in the propagation of deformation in sedimentary basins. A first example was published in the framework of the collaboration Italy-China (Ye et al., submitted).
These results were presented at the 3rd Annual IGCP-641 workshop held in Alicante on 16 November 2017. The presentations can be downloaded from the project website at http://www.igcp641.org/?page_id=1224 (some may require the password IGCP641_pdf available to the project participants to protect some intellectual property submitted to scientific journals). Publications have been submitted to WRR, Eng. Geology, Remote Sens. of the Environ., and presented in various national and international workshops and conferences.

3.2. Detailed list of IGCP project meetings/symposia and IGCP related meetings/symposia with exact attendance (if possible) and number of countries

1.- Session NH021 Subsidence: Causes, Impacts, Mapping and Ground/Satellite Monitoring – 2017 AGU Fall Meeting – 11–15 December 2017, New Orleans, USA.
2.- Session H4 Urban flooding and geo-hazard, MODSIM 2017, 3-9 December 2017, Hobart, Australia.
3.- 3rd IGCP641 Annual Meeting. 16-17 November, 2017. Alicante, Spain. 35 attendants from Spain, Mexico, USA, Italy, China, Japan, The Netherlands, Egypt, Pakistan, Poland, Taiwan, Colombia.
4.- Workshop on Land Subsidence induced by fluid extraction (LASER2017) 14 November 2017. Organized by the Geological Survey of Spain, Madrid, Spain. 60 attendants mainly from Spain and Mexico, USA, Italy, China, Japan, The Netherlands, Egypt, Pakistan, Poland, Taiwan.
5.- National Congress on Land Subsidence in The Netherlands. Heel Holland Zakt (All Holland sinks). 9 November, 2017. Rotterdam, The Netherlands. 300 attendants. Mainly people from Holland, Italy, Mexico.
6.- Special Session. (SE19): IGCP 641 Project M3EF3. Assessment of risks related to ground fracturing and faulting in urban areas. Annual Meeting of the Mexican Geophysical Union (RAUGM) 2017. Puerto Vallarta Jalisco, Mexico. 27 October, 2017. 35 attendants. Mainly people from Mexico, Italy.

7.- 1st International Workshop on Earth Fissures. 13 April 2017. Nanjing, China. Organized by the Key Lab on Earth Fissure Geological Disaster, Ministry of Land Resources. 40 attendants mainly from China and from Italy, Mexico.

8.- 1st International Workshop on Urban Geology. 10-12 April 2017. Shanghai, China. Organized by the Shanghai Geological Survey. 150 attendants mainly from China and from Italy, Mexico.

3.3. Educational, training or capacity building activities related to the IGCP project and IGCP project participants.

- ***In Italy***: two PhD students (Andrea Franceschini and Matteo Frigo) have worked on the project, developing specific expertise on numerical modelling. Lessons on geomechanics are provided to master students within the Numerical Analysis course, Civil and Environmental Engineering degree. A PhD student from Iran (Mohsen Rafiee, University of Isfahan) will conduct part (6 months, from January to June 2018) of his PhD training at Padova University working on the IGCP641 issue;
- ***In China***: Dr. Yue Luo and one PhD student (Zhecheng Wang) have worked on the project, developing specific expertise on numerical modelling. Three MSc students (Wei Wang, Shikang Bao and Yueting Li) have worked on the project, developing earth fissure numerical models in Wuxi case, China. One undergraduate student (Yanlei Wang) took the degree on developing a database of ground rupture occurrence in the World. Meetings with PhD and MSc students were carried out at the Nanjing University, Jiangsu Geological Survey, and Capital Normal University (Beijing). Invited lectures of numerical modelling of land subsidence and earth fissures to the staff of Chinese Geological Survey was given by Shujun Ye on 12-13 September 2017 in Beijing. Staff from the Jiangsu Geological Survey (Nanjing), Shanghai Institute of Geological Survey, Beijing Institute of Hydrogeology and Engineering Geology, China Institute of Geo-Environment Monitoring (Beijing) became involved in the project;
- ***In Mexico***: one PhD student (Gil Ochoa) has specifically worked on the project, with a particular focus to the rupture occurrence in Queretaro. Lessons on fissure mechanisms and lab testing have been provided to students in Geology at UNAM Queretaro. Meetings with the public and governmental administrations about the risk of fissure occurrences and related hazards have been carried out at Iztapalapa Delegation, Mexico City. One MSc student (Felix Centeno) developed an inversion algorithm to improve GPR prospecting for the characterization of fractures and subsoil physical properties;
- Third Workshop of the IGCP 641 Project at the University of Alicante, Spain (https://web.ua.es/es/m3ef3/news.html) included the participation of MSc students from the University of Alicante (Engineering Department) and staff of the Geological Survey of Spain;

3.5. Participation of scientists from developing countries.

There is no doubt that young scientists greatly helped to conduct activities related with this project. Work conducted from University of Padova PhD students was essential to achieve our goals in term of modelling. The majority of the female participants are from developing countries. The above table shows only those participants registered on the webpage of the project. There are actually more people involved, especially many students from the universities and institutes. Taking the Nanjing University as an example, **there are 6 *young scientists/students (<35 years old) working on this project.*** *As we know there are some young scientists/students working on the project in the Capital Normal University in Beijing and Chang'an University in Xi'an. For the women scientists, young scientists and/or scientists from developing countries, they conducted the specific research on survey, monitoring, lab test, numerical modeling etc. in the project, and at the*

same time they understood the involved problems and built up their own capacities respectively.

3.7. Activities involving other IGCP projects, UNESCO programmes, IUGS Commissions or Task Groups or others

- A first contact and a skype meeting have been carried out on February 2017 with Professor Daniela Blessent, leader of IGCP636, and her colleagues/students (Sebastian Rendon Arboleda and others - Universidad Nacional de Colombia). We agreed on the possibility in the near future to exchange students and expertise in relation to modelling geomechanical issues related to fluid withdrawal/injection from/into subsurface reservoirs.

3.9. What tangible improvements has your project obtained?

The research has produced a few major scientific advances: a novel (and unique up to now) approach to model rupture development in real 3D geologic setting; an innovative methodology to detect ground ruptures by FFT processing of satellite SAR solutions; an original technique to process drone acquisitions for the volumetric characterization of ground ruptures.
The fracture map of Mexico city indicated that the building damage caused by the 19th September earthquake 1985 was repeated during the 19th September 2017 earthquake. This map had a strong social impact in Mexico because it was published just before the 19th September 2017 earthquake and indicated the fractures associated to the land subsidence have weakened the part of the city subsoil and had to be taken into account for the reconstruction after the September 2017 earthquake. It is evident from the map that the urban damage is spatially related with the distribution of fractures, which should be considered at high risk areas in the reconstruction plan of the city.

The fracture map of Mexico City had a strong social impact because of the 19th September 2017 earthquake. It is evident that urban damage is spatially related with the distribution of fractures, so as it was during the 19th September earthquake 1985. Ground fractures associated to land subsidence have weakened the part of the city subsoil and should be considered at high risk areas in the reconstruction plan of the city.

A new an important collaboration is started with a group of researchers from Pakistan, University of Balochistan. Many cities are affected by land subsidence and earth fissures, with consequences that are threatening the population. In Quetta, for example, ground ruptures have destroyed private and public buildings and damaged the sewage system yielding a public health crisis because of the rapid infiltration of wastewaters through the fissures and the consequent aquifer contamination. A first contact has been established with the scientists from Iran. Together with China, Mexico and southwest USA, Iran is one of the countries most affected by ground rupture because of the aquifer overexploitation.

IGCP 641 Project leaders also supported the preparation of a proposal for the IGCP Project on Land Subsidence in Coastal Regions leaded by the Key Laboratory of lands subsidence and earth fissures of Shanghai, China and co-leaded by the experts from Italy, the Netherland, and Indonesia.

3.10. What kinds of activities in respect to the benefit of society and science outreach has your project undertaken?

Dissemination of information to local authorities is of the most importance so as free access to the maps of fracturing. The National Disaster Prevention Center of Mexico (CENAPRED)

integrated the map of fractures to the National Risk Atlas that can be free consulted and manipulated thanks to a GIS server. Several meetings have been carried out with key staff of a number of governmental agencies in China directly involved in managing ground rupture occurrence (Jiangsu Geological Survey, Shanghai Institute of Geological Survey, Beijing Institute of Hydrogeology and Engineering Geology, China Institute of Geo-Environment Monitoring). Projects are just started or are in the way of being finalized between these agencies and Chinese and abroad universities to develop detailed monitoring and modeling studies aimed at predicting ground fissures and reducing their hazard.

The leaders of the project had been Invited to give dissemination talks in different events:

1. Dora Carreon-Freyre. Land Subsidence induced by groundwater extraction and associated ground fracturing in Central Mexico Workshop on Land Subsidence induced by fluid ExtRaction (LASER2017) 14th November 2017 organized by the Geological Survey of Spain, Madrid, Spain. http://www.igme.es/laser2017/program
2. Dora Carreon-Freyre Land Subsidence and associated ground fracturing: Study cases in Central Mexico. Keynote. National Congress on Land Subsidence in The Netherlands (Heel Holland Zakt – All Holland sinks). 9 November, 2017. Rotterdam, The Netherlands.
3. Pietro Teatini Monitoring and modelling of Land Subsidence and associated ground fracturing Italy. Keynote. National Congress on Land Subsidence in The Netherlands (Heel Holland Zakt – All Holland sinks). 9 November, 2017. Rotterdam, The Netherlands.
4. Dora Carreon-Freyre. Monitoring of Land Subsidence and associated ground fracturing. Study cases in central Mexico. 36th Conference on Surveying and Geomatics: “Measure the world, Measure the future” 31th August, 2017. Department of Geomatics, National Cheng Kung University. Taiwan, China.
5. Dora Carreon-Freyre. The Centre of Geological Risk Evaluation CERG in Iztapalapa, Mexico City: Land Subsidence and Associated Fracturing Studies. Keynote. International Workshop on Earth Fissures Geological Disaster, Nanjing, China. 13th April, 2017. Nanjing University-Geological Survey of Jiangsu Province.
6. Dora Carreon-Freyre. The UNESCO Working Group on Land Subsidence: activities aimed at improving global knowledge, related phenomena and social implications in urban areas, the case study of Mexico City. Keynote. 1st. International Symposium on Urban Geology: Land Subsidence and City Security. 11th April, 2017. Shanghai, China. Shanghai Institute of Geological Survey. Key Laboratory of Land Subsidence Monitoring and Prevention. Ministry of Land and Resources of China.
7. Pietro Teatini. Present challenges in modelling geomechanical issues related to fluid withdrawal/injection from/into subsurface reservoirs. Keynote Lecture at the Annual Meeting of the Mexican Geophysical Union (RAUGM) 2017. Puerto Vallarta Jalisco, Mexico. 27th October, 2017.
8. Shujun Ye. Numerical Simulation of regional land subsidence in the Yangtze Delta area, China. 36th Conference on Surveying and Geomatics: “Measure the world, Measure the future” 31th August, 2017. Department of Geomatics, National Cheng Kung University. Taiwan, China.

3.11. What kind of public information (media reports, etc.) has your project generated? And how do you evaluate their?

The map of fractures of Mexico City had a wide media cover during more than 3 weeks. It was a main heading subject of many TV interviews to Dora Carreon and newspapers notes. A part of them have been stored in the project website (http://www.igcp641.org/?page_id=1140)

3.12. Project highlight: Select one realization that happened during your project this year that you would like to see highlighted on the UNESCO-IGCP website (for example the publication of a book, the release of documentary, a very high profile publication (level Science or Nature),

the unique find of a fossil, etc. You should provide a short text in layman's terms (max. 400 words) and a nice picture or video link, etc. which we can use for the IGCP website.

One of the main outcomes of the IGCP641 project "Mechanisms, Monitoring and Modeling Earth Fissure generation and Fault activation due to subsurface Fluid exploitation (M3EF3)" is the realization of a world map with the location of the main occurrences of ground rupture (Figure 1). To accomplish this goal, an in-depth bibliographic and literature review has been carried out to find the major sites threatened by this geo-hazard. More than 45 sites have been listed, mainly located in China, USA, Mexico, and Iran. This information has been used to develop a first a Google Map-based map of human-induced ground rupture in the world. The map is freely available at http://www.igcp641.org/?page_id=45 in the M3EF3 project website. Two levels of detail are used in presenting the rupture sites. Initially, each site has been identified by a single marker. Then, the trace of the fissures, properly georeferenced, are added where available. For each sites the map is complemented by the following metadata: latitude, longitude, number of ruptures, rupture trend, rupture total length, characteristic slippage and/or opening, rate of land subsidence, cumulative subsidence, mechanisms, time occurrence, and specific scientific references. Obviously, the mapped sites are not intended to provide an exhaustive list. The map will be easily populated by other sites when new information will become available.

Figure 1. World map with the location of the main sites affected by of ground rupture reported in scientific litterature. The amplified area showing the distribution of fractures on the Xi'an City, China is presented in the square at the right upper corner of the figure. The map is freely available in the IGCP641 project website. (http://www.igcp641.org/?page_id=45);

4. Activities planned

4.1. General goals

- Establish and/or improve the collaboration with researchers from Iran, India, South Africa, Saudi Arabia;
- Update the Ground Rupture World Map;

- Foster enrolment of students/young researchers in developing/newly-developed countries strongly affected by ground ruptures and land subsidence (Mexico, China, Iran, Pakistan);
- Possibly publish a book on IGCP641 issues and results. Contacts are ongoing with an acquisitions editor at CRC Press/Balkema, Taylor & Francis Group;
- Continue with the numerical modelling applications;
- Organize a session on Land Subsidence and ground ruptures at the AGU Fall Meeting 2018.

6. Request for extension, on-extended-term-status, or intention to propose successor project

We would like to finish this phase during 2018 to continue the research work on modelling and better identify the mechanisms responsible for the generation of ground fractures.

We are planning to prepare a second phase proposal specifically focused on fractures and reactivation of faults related to groundwater exploitation, the application of M3 integrated approach to the new sites using a GIS-based risk assessment tool and to improve the dissemination work through workshops, undergraduate and postgraduate courses, non-technical fact sheets for policy makers and citizens, and through guidelines for laboratory, monitoring, and modelling investigations.

The expected ultimate societal achievement include the use of M3EF3 outcomes to establish management, public policies and possible regulatory criteria in urban/agricultural/industrial planning; with respect to the development of subsurface fluid resources and the identification of effective mitigation strategies of accompanying ground failures.

7. Financial statement ($ USD only)

The IGCP Scientific Board would like to be informed how the IGCP funds were used.
Of the allocated resources provided by IGCP (3000 USD, minus wire-transfer and currency exchange fees), was used for the Annual IGCP641 Workshop in Alicante and the field trip to the Guadalentin Valley, Murcia.

About 40%, was used to allow the participation of an early career researcher from Pakistan (flight tickets). The other 60% was used to cover the 2-day workshop expenses (meal and part of the logistic). Rooms for the event and web-domain (https://web.ua.es/es/m3ef3/) were provided for free by the University of Alicante; expenses for folders, notebooks and pens were covered by local Cátedra de Movilidad Vectalia, Romanense de Mármoles S.L.

ANNEX No. 2: Publication List

Galloway, D.L., and Leake, S.A., 2017, Regional land subsidence caused by the compaction of susceptible aquifer systems accompanying groundwater extraction: in Singh, V.P. (ed.), Handbook of Applied Hydrology (2nd edn.), chpt. 56, McGraw-Hill Education, New York, p. 56.1–56.11.

Teatini, P., Carreon-Freyre D. Ochoa-Gonzalez, G, Shujun, Y., Galloway, D., Hernandez-Marin, M., Ground ruptures attributed to groundwater overexploitation damaging the Jocotepec city in Jalisco, Mexico: 2016 field excursion of IGCP-641. Accepted in Episodes Journal of International Geoscience, IUGS. E-17-13, for publication in March, 2018.

Hernandez Marin, M., Pacheco Martinez, J.., Burbey, T.J., Carreon-Freyre, D., Ochoa-Gonzalez, G, Campos-Moreno, G.., de Lira, P., Evaluation of subsurface infiltration and displacement in a subsidence-reactivated normal Fault in the Aguascalientes Valley, Mexico. Accepted in the Journal Environmental Earth Sciences, Springer.

Ochoa-Gonzalez, G., Carreon-Freyre, D., Franceschini, A., Cerca, M., Teatini, P. Overexploitation of groundwater resources in the faulted basin of Querétaro, Mexico: a 3D deformation and stress analysis. Submitted to Engineering Geology, Elsevier.

Hernandez Marin, M., Pacheco Martinez, J.., Burbey, T.J., Carreon-Freyre, D., Ochoa-Gonzalez, G, Campos-Moreno, G.., de Lira, P., Evaluation of subsurface infiltration and displacement in a subsidence-reactivated normal Fault in the Aguascalientes Valley, Mexico. Journal Environmental Earth Sciences.

S. Ye, A. Franceschini, Y. Zhang, C. Janna, X. Gong, J. Yu, and P. Teatini, A novel approach to model earth fissure caused by extensive aquifer exploitation and its application to the Wuxi case, China, Water Resources Research. Under review.

Map of ground fracturing in Mexico City. The map was included in the National Atlas of Risks (http://www.atlasnacionalderiesgos.gob.mx).Technical report, a publication is under preparation;

Abstracts in the Special Sessions

- (SE19): IGCP 641 Project M3EF3. Assessment of risks related to ground fracturing and faulting in urban areas. Annual Meeting of the Mexican Geophysical Union (RAUGM) 2017. Puerto Vallarta Jalisco, Mexico. 27Th October, 2017. i*n Spanish.*

- Centeno Salas, F.**,** Carreón Freyre, D., Gutiérrez Calderón, R., 2017. Geofísica de alta resolución para el estudio de la deformación y fracturamiento del subsuelo en la zona Tláhuac, Ciudad de México. i*n Spanish.*

- Gutiérrez - Calderón, R., Alcántara Durán, C., Carreón Freyre, D., Cerca, M., Espinosa Severino, O., Espinosa Valle, M.F., 2017. Caracterización morfológica y fracturamiento asociado con estructuras antiguas en la Ciudad de México. .i*n Spanish.*

- Alcántara Durán, C., Gutiérrez Calderón, R., Sánchez Luna, E., Lazcano Sánchez, J., Carreón Freyre, D., 2017. Técnicas de percepción remota aplicadas a la delimitación de microcuencas asociadas a subsidencia y fracturamiento en la zona central de Iztapalapa, Ciudad de México. i*n Spanish.*

- Carreón Freyre, D., Cerca, M.., Gutiérrez Calderón, R., Ochoa González, G., 2017. Condiciones de fracturamiento de los sedimentos lacustres de la Ciudad de México.
- González Hernández, M., Carreón Freyre, D., Zacarías Ramírez, S., Gutiérrez Calderón, R., 2017. Análisis del fracturamiento en las zonas aledañas al Peñón del Marques y al Peñón de los Baños en la Ciudad de México. i*n Spanish.*

- Zacarías Ramírez, S., Gutiérrez Calderón, R. González Hernández, M., Carreón Freyre, D., Alcántara Durán, C., Jiménez Sánchez, A., 2017. Análisis de vulnerabilidad social asociada al fracturamiento del subsuelo en la Delegación Iztapalapa, Ciudad de México. *in Spanish*.

- Frigo, M., Ferronato, M., Carreon-Freyre, D., Ye, S., Galloway, D. and Teatini, P. Ground ruptures and intensive groundwater use in urban zones: a parametric FE-IE modelling investigation. Contribution n. H4.978, MODSIM 2017, Australia.

-Shujun Ye, Andrea Franceschini, Yan Zhang, Carlo Janna, Pietro Teatini, Xulong Gong, Jun Yu. Numerical simulation of earth fissures caused by overly aquifer exploitation at Guangming Village, China. NH31B-0221, AGU 2017, USA.

Related publications in 2017

- Castellazzi, P., Garfias, J., Martel, R., Brouard, C., Rivera, A.I 2017. Support sustainable urbanization over compacting aquifers: The case of Toluca Valley, Mexico. International Journal of Applied Earth Observation and Geoinformation.Volume 63, 2017, Pages 33-44.

- Yoo, J., Perrings, Cha. 2017. An externality of groundwater depletion: land subsidence and residential property prices in Phoenix, Arizona. Journal of environmental economics and policy. Volume 6. Number 2.

- Yoo, J., Frederick, T., 2017.The varying impact of land subsidence and earth fissures on residential property values in Maricopa County – a quantile regression approach. International Journal of Urban Sciences. Volume 21, 2017 - Issue 2.

ANNEX No. 3. The Land Subsidence International Initiative (LaSII). Proposal

UNESCO-IHP WGLS, 23rd November, 2017

Land subsidence (the loss of land elevation) is a major problem that threatens viability and sustainable economic development for many millions of people throughout the world, especially, but not restricted to coastal and highly urbanized areas.

The UNESCO Working Group on Land Subsidence (WGSL) is one of the oldest working groups within the International Hydrological Programme (IHP), initiating activities during the 1965-1974 International Hydrological Decade (IHD): Experimental Basins, World Water Balance and Water Resources of the Earth. In the 1970s the WGLS started its activities to improve and disseminate knowledge on land subsidence, mainly in developed and newly-developed countries and regions, e.g., Japan, The Netherlands, USA, Italy, Mexico, China, Taiwan that were strongly affected by land subsidence following the economic boom after the World Wars.

Since 2010 the members of the WGLS established new linkages and collaborations with other international and national hydrologic programs and projects concerned with the sustainable development of global land and freshwater resources and the subsidence hazards accompanying their exploitation. Now, facing global changes the need to disseminate this knowledge more broadly and to intensify applications of the accumulated knowledge is urgent.

Because of the strong anthropogenic component of the prevalent subsidence processes, the activities of the LaSII would be aligned implicitly with the goals elucidated in the Focal Areas 1.1, 1.2 and 1.3 of Theme 1 and explicitly in the goals stated in the Focal Areas 2.1, 2.2 and 2.3 of Theme 2, and different Focal Areas of Themes 4 and 5 of the ***IHP-VIII Phase Strategic Plan (2014-2021) ¨Water security: Responses to local, regional, and global challenges":***

> *Theme 1: Water-related Disasters and Hydrological Change*
> Focal Area 1.1 Risk management as adaptation to global change
> "The number of human losses and economic damage linked to human practices, such as groundwater overexploitation, has been exacerbated by water-related extreme events and sea level rise. There is a need to establish methodologies to assess risk considering the hydro-climatological and social conditions of the area of concern. Integrating pilot case studies on hazard-damage relationships on local/regional scales and developing hazard-damage relationships are essential to providing risk management tools for water managers and policy makers".
> Focal Area 1.2 Understanding coupled human and natural processes
> Focal Area 1.3 Benefiting from global and local Earth observation systems
>
> *Theme 2: Groundwater in a changing environment*
> Focal area 2.1 Enhancing sustainable groundwater resources management
> Focal area 2.2 Addressing strategies for management of aquifers recharge
> Focal area 2.3 Adapting to the impacts of climate change on aquifer systems
> "To calibrate hydrological models for simulation of spatially and temporally changing groundwater recharge, discharge and storage and inclusion of a groundwater component into land surface models require improvements in terrestrial and satellite based groundwater monitoring and monitoring data assessment and management. Coastal aquifers prone to depletion and accompanying land-level lowering contributing to sea-level rise need particular attention".

Theme 4: Water and human settlements of the future
"Today, cities all over the world are facing a range of dynamic regional and global pressures, such as climate change, population growth, deterioration of urban infrastructure systems and more".
Theme 5: Adapting to the impacts of global changes on rivers basins and aquifer system Focal area 1.1 Global changes and feedback mechanism in hydrogeological processes in stressed systems

Why Land Subsidence (LS) is Still a Critical Societal Issue

Society is facing a large number of challenges related to our sustainable use of land and water resources that will increase in the next decades. The effects of climate change in terms of sea-level rise and variation in the distribution and timing of precipitation, runoff and recharge, are compounded by the increasing concentration of population in (mega-) cities and elsewhere along the coasts of the world. The consequences related to the expanding need of freshwater resources in even more concentrated, at-risk zones of the world will inevitably affect a growing number of people. A few example case studies clarify the present criticality of the LS issue worldwide:

— in Jakarta, Indonesia, where the population grew from 8.2 million to more than 30 million from 1970 to 2016, groundwater extraction for drinking and industrial water supply has caused the sinking of land surface at rates of 10-20 cm/yr. This is an order of magnitude larger than the rate of sea-level rise. The effects on vulnerability to flooding from river and sea waters are increasing dramatically, especially in portions of the city that have subsided as much a 2 m below sea level. Moreover, houses, buildings and urban infrastructures are being increasingly damaged or destroyed as a result of LS;
— in many deltaic and coastal areas of the world (e.g., the Bengal, Mekong, Nile, and Mississippi river deltas; the coastland in The Netherlands) engineered surface-water drainages and lowering of the phreatic groundwater is promoted to optimize agricultural production in the short term. LS occurs as a result of compaction and oxidation of the drained, usually organic-rich (peat) soils, CO_2 emissions to the atmosphere increase, valuable ecosystems are lost, and vulnerability to coastal and riverine flooding is enhanced;
— in numerous regions in the world large earth fissures, ground fractures and the reactivation of regional faults occurs as a result of the deformation of aquifer systems and LS accompanying the over-exploitation of groundwater supplies. Earth fissuring is damaging structures and infrastructures in Xi'an, China, posing a significant risk to humans living in these regions. In Quetta, Pakistan with a population of more than 1,000,000 inhabitants and where a large number of them rely solely on groundwater for domestic and agricultural water supplies, ground fractures have recently compromised the city sewage system yielding a public health crisis because of the rapid infiltration of wastewaters through the fissures and the consequent aquifer contamination;
— in Mexico City many buildings and more than 20,000 houses collapsed or were severely damaged because during the September 19th, 2017 earthquake in areas where the subsoil was strongly weakened by ground fractures that previously developed with the more than 10 m of LS accompanying groundwater exploitation that accumulated in the city since the middle of the last century.

These examples clearly show that historic and current unsustainable use of groundwater resources is leading to high direct and indirect socioeconomic costs, mainly threatening disadvantaged populations in newly developed and developing countries. Furthermore, the consequences are expected to increase in the next decades. The cost of not working towards a sustainable water management include the need for developing countermeasures to maintain habitability in the coastal cities by building high(er) dikes—however, with much more damages and deaths in the case of failure, restoring damaged buildings, water wells, sanitary and storm sewer systems, pipelines, roads, railways, bridges, canals, stream channel levees, and installing new deeper drainage systems.

Economic Impact

Despite the facts that the scientific basis of aquifer-system compaction and LS due to groundwater pumping, and the means to mitigate its occurrence are well known, the process is increasingly affecting more and larger regions and with greater consequences throughout the world. In the IHP-VIII Phase Strategic Plan which addresses Water Security, LS is considered as a major threat.

Nevertheless, the attention afforded by LS in sustainable planning of water services and safe urban development is still undervalued. Although difficult to quantify, the direct and indirect costs associated to damages caused by land subsidence are extremely large. Here a few examples: 2500 M€/year in China; 1092 M€ (1300 M$) from 1955 to 1972 in the San Joaquin Valley, USA; 360 M€/year in Poland; 50 M€ from 1992 to 1995 in Murcia City, Spain; 52 B€/year in The Netherlands (the national planning bureau PBL, Netherlands Environmental Assessment Agency calculated that in the Netherlands, the cost for society of land subsidence occurring in peatlands amounts to billions of Euros).

Why the WGLS is Uniquely Positioned to Lead the Development of a UNESCO Land Subsidence International Initiative (LaSII)

Until now, a still growing group of scientists from all over the world have – on a voluntary basis – joined in the WGLS. They look to share their knowledge, mainly collected through individual research projects and enhance subsidence awareness by:

- — publishing a guidebook on land subsidence;
- — convening annual WG meetings;
- — organizing, sponsoring and convening a 5-yearly international symposium on land subsidence over five decades (the ninth held at Nagoya, Japan, in 2015 and the tenth will be held in The Netherlands in 2020);
- — establishing a growing number of collaborations with other local, state and national subsidence-interest groups, and several collaborative projects;
- — through the implementation and updating of a WG website (http://landsubsidence-unesco.org/) with general informative material on the process, a worldwide map of the land subsidence occurrences, the proceedings of the past nine symposiums on land subsidence, scientific articles and technical reports.

As a LaSII the group of experts and collaborators will seek stronger support from the UNESCO IHP and the governments of the 11 countries that are now participating, to consolidate the development of methodologies for characterization and modeling of LS, monitoring networks, transfer of information to decision makers, advise creation of public policies and ideally, in the end contribute to an increase in the security and resilience of inhabitants of LS affected areas. Moreover, there is an urgent need to transfer the generated knowledge to developing countries with limited access to research studies and monitoring. The main goals are to improve access to scientists and engineers from developing countries, enhance knowledge transfer and better planning for the sustainable use of the groundwater resources LS-affected regions in view of the expected climate changes.

LaSII would focus primarily on three main aspects:

1. LS in coastal areas, related with sea-level rise,
2. LS related with earth fissures, ground fractures and fault reactivation,
3. LS related with water security in urban areas.

Activities:

The WG participants are also involved in other UNESCO-related proposals, such as the constitution of a UNESCO International Category 2 Center on Land Subsidence in Shanghai, China and, the development of UNESCO-IGCP projects on specific subjects.

Main goals to achieve:

- Propose effective methodologies for identifying and establishing an inventory of subsiding areas in the world and present publications with relevant case studies,
- Publish guidelines for the identification, investigation, development and management of strategic LS phenomena to be used in emergencies that result from critical deformation (earth fissuring, faulting, ground fracturing),
- Improve predictability and monitoring of land-level lowering by using *in situ*, new measurement technologies and promote local use of satellite information (remote sensing imagery) for land-level monitoring and groundwater management,
- Develop methods to assess the impacts of groundwater withdrawal and analysis of the associated risks,
- Develop indicators to assess the impacts of groundwater withdrawal on water resource systems,
- Use measured deformation to help characterize aquifer systems to better quantify sustainable yield and predict future subsidence trends
- Support capacity building in member countries in order to gain and advocate better understanding and handling of hazards, vulnerabilities and benefits involving LS and other groundwater-related disasters.

- Better define growing population pressure on groundwater resources, global warming impacts on groundwater depletion, rising sea level and saltwater intrusion, and bring together country/regional assessments via seminars, conferences, etc.
- Develop networks to exchange information on best practices in countries with similar conditions of LS related to groundwater withdrawal,
- Raise awareness of decision makers, implementers, users and the general public of the importance of groundwater as a store of freshwater in order to encourage improved protection and sustainable exploitation of groundwater — through leaflets, publications, the media, education and training,
- Strengthen capacity building and educational capabilities in urban water management aimed at relevant target groups, including decision makers, planners and practitioners, with a special emphasis on developing countries,
- Facilitate participation of IHP Focal Points and National Committees in the development of case studies and the dissemination of LS mitigation guidelines,
- Develop linkages with other IHP Programs: ICHARM (International Centre for water Hazard And Risk Management) and FRIEND (Flow Regimes from International Experimental and Network Data), HELP (Hydrology for the Environment, Life and Policy) and Urban Water Management (UWMP) and with international institutions (i.e. International Association of Hydrogeologists, International Society of Soils Mechanics and Geotechnical Engineering, Eurogeosurveys).

ANNEX No. 4. Newspaper notes on the fracture map of Mexico City

From 12-16 October, 2017

www.dgcs.unam.mx/boletin/bdboletin/2017_677.html

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Boletines Recientes

Boletín UNAM-DGCS-677
Ciudad Universitaria.
06:00 hs. 12 de octubre de 2017

Dora Carreón Freyre

MAPEA UNAM FRACTURAS EN EL SUELO DE LA CIUDAD DE MÉXICO

• Esta información es valiosa para la planeación de la reconstrucción de la urbe luego del sismo del pasado 19 de septiembre, dijo Dora Carreón Freyre, investigadora del Centro de Geociencias

• La extracción del agua es el factor que detona y pone en evidencia las debilidades que ya existían en el suelo, pues por el estrés hídrico el subsuelo se consolida y compacta, y las irregularidades y discontinuidades comienzan a manifestarse o propagarse hacia la superficie

Un mapa que permite conocer en dónde se ubican las principales fracturas que afectan la infraestructura de la Ciudad de México, información altamente valiosa, sobre todo ahora para la planeación de la reconstrucción de la urbe luego del sismo del pasado 19 de septiembre, fue terminado por expertos del Centro de Geociencias (CGeo) de la UNAM.

Dora Carreón Freyre, investigadora de la entidad universitaria y responsable académica del Centro de Evaluación de Riesgo Geológico (CERG) de la delegación Iztapalapa, recordó que este trabajo inició a finales de 2016, como parte de un proyecto impulsado por el Centro Nacional de Prevención de Desastres (Cenapred) y la UNAM.

El proyecto ha permitido identificar la vulnerabilidad física del suelo de la Ciudad de México (susceptible a fracturarse) y estimar la fragilidad social en zonas de fracturamiento, pues este problema afecta de diferente manera a la población, dependiendo del nivel socioeconómico.

Hay gente que dedica una parte importante de sus ingresos para levantar una barda o construir un cuarto, así que su resiliencia ante una contingencia es distinta a la de la población económicamente más estable, detalló.

La universitaria ha trabajado en estos temas en la Ciudad de México desde 2007, cuando una fractura que se abrió repentinamente en la delegación Iztapalapa llevó al establecimiento del CERG. "Se realizó el mapa de fracturas en esa demarcación entre 2008 y 2012, años en los que se laboró con los delegados en turno para contribuir a disminuir el riesgo asociado para la población mediante una zonificación adecuada y el diseño de distintas medidas de mitigación".

Esto fue lo que llevó al Cenapred a buscar al equipo de Carreón Freyre, con el objetivo de ampliar la búsqueda y cartografía de dichas fracturas que, se encontró, afectan a 15 de las 16 delegaciones de la CdMx, aunque las que tienen mayor número son Benito Juárez,

Mapa de las fracturas que afectan el territorio de la Ciudad de México, elaborado por el CGeo. Se muestra el relieve de la urbe y las fallas geológicas regionales.

Tweets by @SalaPrensaUNAM

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EL UNIVERSAL
CIENCIA Y SALUD
UNAM mapea fracturas en el suelo de la Ciudad de México
Esta información es valiosa para la planeación de la reconstrucción de la urbe luego del sismo del pasado 19 de septiembre
PATROCINADO
interjet
Un mapa que permite conocer en dónde se ubican las principales fracturas que afectan la infraestructura de la Ciudad de México fue terminado por expertos del Centro de Geociencias (CGeo) de la UNAM.
El proyecto permitió identificar la vulnerabilidad física del suelo de la Ciudad de México y enfocar la fragilidad social en zonas de fracturamiento, pues este problema afecta de diferente manera a la población, dependiendo del nivel socioeconómico.
Sobre el origen de las fracturas en nuestra metrópoli, la investigadora precisó que el principal motivo es el contraste entre los materiales volcánicos y los de relleno del lago.
"Se debe estudiar cada zona, porque los contactos litológicos son planos de debilidad, con una distribución distinta en las zonas de transición o de pie de sierra, montañosas o lacustres. Por ello, además de conocer los efectos de los sismos en estos tipos de suelo, es importante saber qué tan susceptibles son de fracturarse", explicó
Doña Carmen Reyes, investigadora y responsable académica del Centro de Evaluación de Riesgo Geológico (CERG) de la delegación Iztapalapa.
Fracturamiento
Simbología
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Concluyen mapa de fracturas que afectan la infraestructura de la CDMX


Marina encabeza operativo y abatió


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Mapea UNAM fracturas en el suelo de la CDMX
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UNAM HACE MAPA DE LAS FRACTURAS DEL SUELO EN LA CDMX

La Universidad Nacional Autónoma de México (UNAM) terminó un mapa de las fracturas del suelo de la Ciudad de México (CDMX)para conocer las principales fallas geológicas.

La información, recabada por científicos del Centro de Geociencias de la UNAM, permitirá una mejor planeación para la reconstrucción de la infraestructura tras el sismo del 19 de septiembre.

Dora Carreón Freyre, responsable académica del Centro de Evaluación de Riesgo Geológico (CERG) de la Delegación Iztapalapa, recordó que este trabajo inició a finales de 2016, como parte de un proyecto impulsado por el Centro Nacional de Prevención de Desastres (Cenapred) y la UNAM.

La investigación ha permitido identificar la vulnerabilidad física del suelo de la CDMX (susceptible a fracturarse) y estimar el grado de afectación en los diferentes estratos sociales.

> "Hay gente que dedica una parte importante de sus ingresos para levantar una barda o construir un cuarto, así que su resiliencia ante una contingencia es distinta a la de la población económicamente más estable", detalló Dora Carreón.

El mapeo arrojó que 15 de 16 delegaciones se encuentran afectadas por las fallas en el suelo, aunque las que registran una mayor cantidad son Benito Juárez, Cuauhtémoc, Iztapalapa, Tláhuac y Xochimilco.

> "La distribución de las fracturas en la base de la ladera de la Sierra de Santa Catarina, en Iztapalapa, es muy similar del otro lado, en

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En cinco delegaciones de la Ciudad de México están las principales fracturas de suelo: UNAM

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FONDEA el periodismo independiente

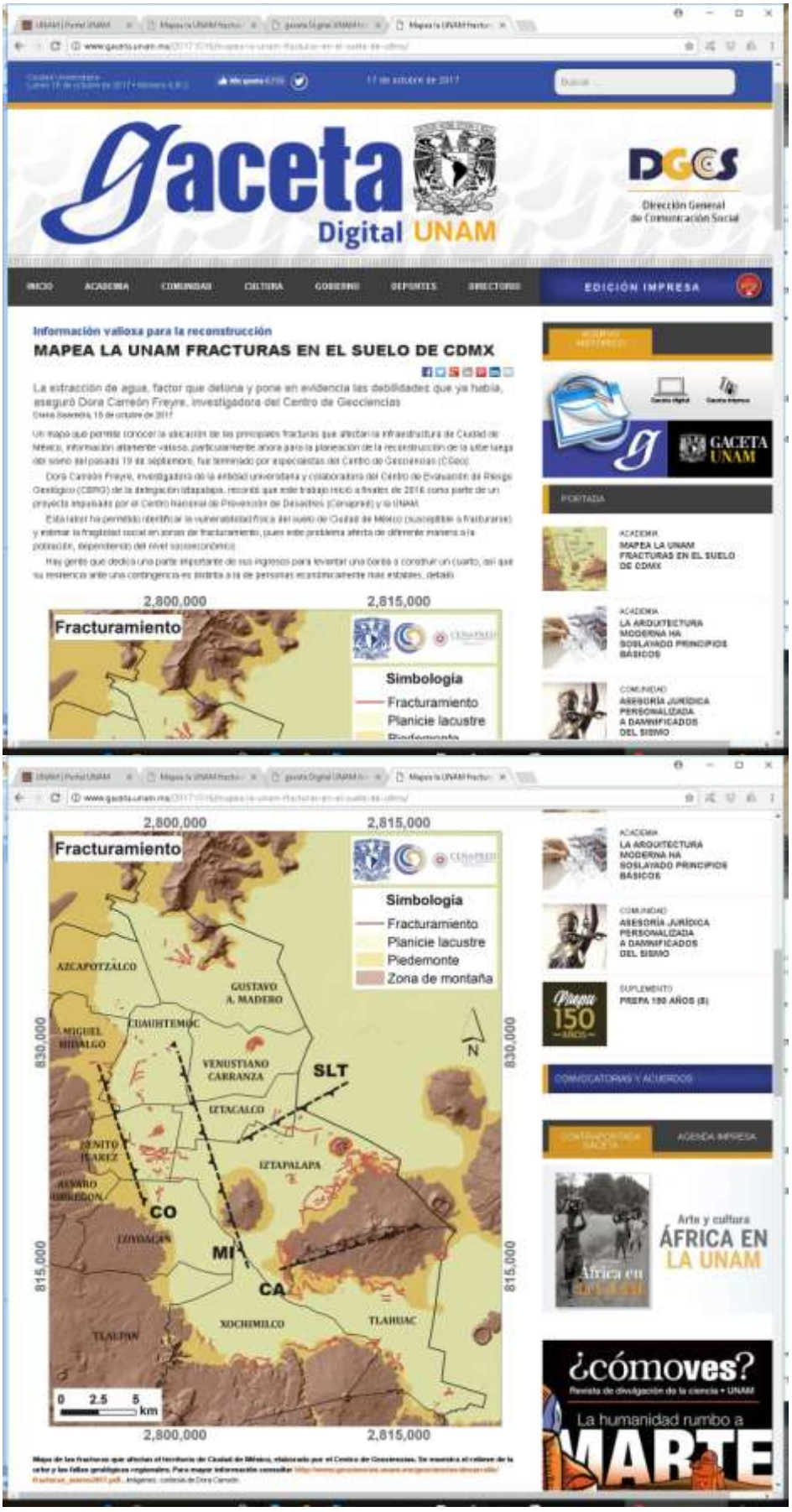
El Centro de Geociencias de la UNAM realizó un mapa que permite conocer la ubicación de los principales fracturas que afectan la infraestructura de la Ciudad de México, en el cual se detalla que 10 de las 16 delegaciones tienen fallas en sus suelos. La institución informó que el documento terminado estará disponible a partir de la próxima semana.

Este proyecto permite identificar la vulnerabilidad física del suelo de la capital del país, el cual es susceptible a fracturarse, y estimar la fragilidad social en zonas de fracturamiento, esto de cara a la planeación de la reconstrucción de la urbe después del sismo del 19 de septiembre.

mayor número de fracturas son Benito Juárez, Cuauhtémoc, Iztapalapa, Tláhuac y Xochimilco. En cuanto a la comparación de los mapas con los sitios dañados por los sismos de 1985 y 2017, se identificó que los edificios colapsados se encuentran en las zonas con más fracturas, principalmente en Benito Juárez y Cuauhtémoc.

"La distribución de las fracturas en la base de la ladera de la Sierra de Santa Catarina, en Iztapalapa, es muy similar del otro lado, en Tláhuac, y también en Xochimilco, en la base de la ladera de la Sierra Chichinautzin. Existe una relación directa entre la aparición de las fracturas y las áreas de contraste entre las zonas del lago y los edificios volcánicos", explicó Dora Carrión Frayre, investigadora de Geociencias, quien añadió que las delegaciones Benito Juárez y Cuauhtémoc se ubican en una especie de fosa delimitada por dos fallas que atraviesan la ciudad de sur a norte.

La científica detalló que la extracción del agua es un factor detonante y que pone en evidencia las debilidades que ya existían en el suelo, pues se genera un estrés hídrico que hace que el subsuelo se consolide y se compacte, lo que permite a las irregularidades y discontinuidades que ya estaban empiezan a manifestarse o propagarse hacia la superficie.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Información valiosa para la reconstrucción
MAPEA LA UNAM FRACTURAS EN EL SUELO DE CDMX
La extracción de agua, factor que detona y pone en evidencia las debilidades que ya había, aseguró Dora Carreón Freyre, investigadora del Centro de Geociencias
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Fracturamiento
Simbología
Fracturamiento
Planicie lacustre
Piedemonte
Zona de montaña
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GUSTAVO A. MADERO
MIGUEL HIDALGO
CUAUHTEMOC
VENUSTIANO CARRANZA
IZTACALCO
BENITO JUAREZ
IZTAPALAPA
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MAPEA LA UNAM FRACTURAS EN EL SUELO DE CDMX
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COMUNIDAD
ASESORÍA JURÍDICA PERSONALIZADA A DAMNIFICADOS DEL SISMO
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Identifica la UNAM grietas en el suelo de la Ciudad de México (+infografía)
Zona de fracturas
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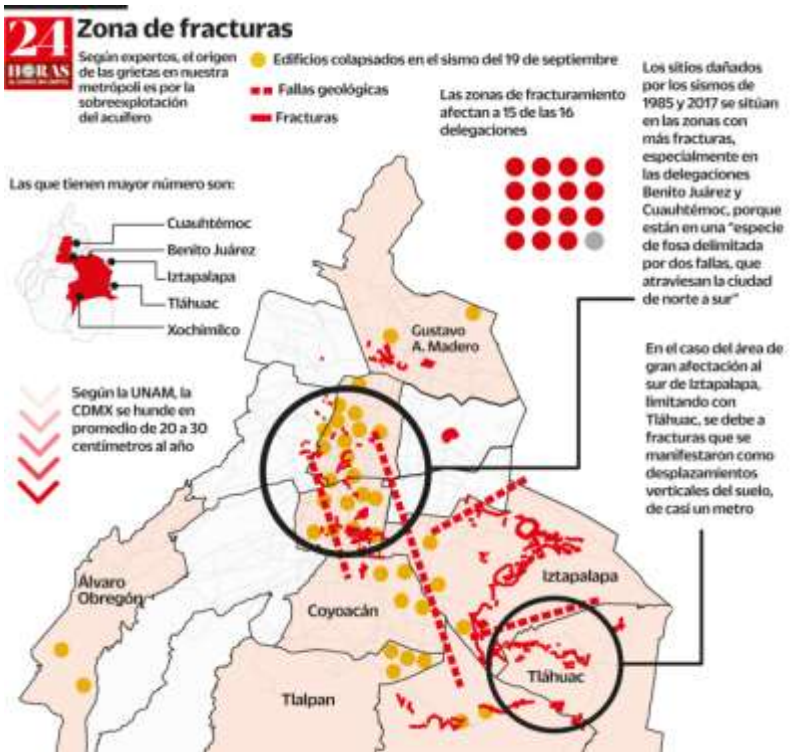
2,442 MXN
¡Reserva Ya!
Notas relativas


Zona de fracturas
Según expertos, el origen de las grietas en nuestra metrópoli es por la sobreexplotación del acuífero
Edificios colapsados en el sismo del 19 de septiembre
Fallas geológicas
Fracturas
Las zonas de fracturamiento afectan a 15 de las 16 delegaciones
Los sitios dañados por los sismos de 1985 y 2017 se sitúan en las zonas con más fracturas, especialmente en las delegaciones Benito Juárez y Cuauhtémoc, porque están en una "especie de fosa delimitada por dos fallas, que atraviesan la ciudad de norte a sur"
Las que tienen mayor número son:
Cuauhtémoc
Benito Juárez
Iztapalapa
Tláhuac
Xochimilco
Gustavo A. Madero
Según la UNAM, la CDMX se hunde en promedio de 20 a 30 centímetros al año
En el caso del área de gran afectación al sur de Iztapalapa, limitando con Tláhuac, se debe a fracturas que se manifestaron como desplazamientos verticales del suelo, de casi un metro
Alvaro Obregón
Coyoacán
Iztapalapa
Tláhuac
Tlalpan