POROMECHANICS V

PROCEEDINGS OF THE FIFTH BIOT CONFERENCE ON POROMECHANICS

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Preface

We are extremely honored, and very happy, to cordially welcome you in the cosmopolitan and culturally rich City of Vienna and at the Vienna University of Technology (TU Wien), the oldest of its type in Central Europe, for the *Fifth Biot Conference on Poromechanics (BIOT-5)*. In 2013, this year marking the 50th anniversary of the death of Karl von Terzaghi (1883-1963), we hold BIOT-5 in memory of this "Grandfather of Poromechanics," the founder of consolidation experiments and theoretical soil mechanics in general (see the Introduction for further historical remarks).

We are very grateful that a significant number of brilliant scientists were ready to organize mini-symposia on topics that they rated as most interesting and stimulating. These mini-symposia are the natural backbone of BIOT-5's scientific program, their titles and organizer affiliations representing the scientific and geographic breadth of BIOT-5 (see the Introduction for all names and further details).

The design and set-up of BIOT-5 was strongly supported by the Local Organizing Committee, the International Scientific Committee, and the Advisory Committee, comprising all the earlier Biot conference hosts, in particular by Franz Ulm (M.I.T.), as well as by Alex Cheng (University of Mississippi) and Younane Abousleiman (University of Oklahoma), the latter two having been so instrumental in launching, with the help of Madame Nadine Biot, the Biot conference series, and staying the ever-motivated "good spirits" behind the scenes.

Setting up an event such as a BIOT-5 requires seamless administrative support. In this context, we are thankful for the help of the Engineering Mechanics Institute (EMI) of the American Society of Civil Engineers (ASCE), in particular to the director of EMI, Amar Chaker, and to its general administrator, Verna Jameson. However, with deepest appreciation, we note that, more than with any other person, the successful realization of BIOT-5 depended on the ceaseless efforts of Martina Pöll (TU Wien/IMWS), whose extraordinary organizational talent and dedication were key to the very existence of Biot-5.

Of course, the success of BIOT-5 will depend on the dedication, motivation, and enthusiasm of its participants. We are very pleased that as many as 297 (mandatory) full papers have been submitted and will be presented, thus keeping up with the Biot conference tradition of providing, in four years intervals, the up-to-date state-of-the-art report on poromechanics, this year published through ASCE. Knowing that writing a full conference paper has become an extraordinary requirement nowadays, the fact that so many world-class scientists were ready to make this effort makes us very optimistic regarding the positive short- and long-term impact of BIOT-5.

Enjoy Vienna and lively discussions on poromechanics at one of its birthplaces!

Christian Hellmich, Bernhard Pichler, Dietmar Adam
Chairmen BIOT-5

Introduction to BIOT-5
in Memory of Karl von Terzaghi and the Viennese "Pre-History" of the Field in the 1930s

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It has become a tradition to open the Biot conferences from a historical perspective, and hence, we will start with some historical background.

The First Biot conference on Poromechanics was held in 1998 at the Université Catholique de Louvain (Belgium), the Alma Mater of Maurice Anthony Biot (1905-1985), the founder of the field that is commonly referred to as Biot theory of poroelasticity, a field with unparalleled impact on a wide variety of disciplines, including civil and biomedical engineering, geophysics, acoustics, and materials science. This first conference, with its truly multidisciplinary nature, was so successful that the poromechanics community continued to meet and exchange ideas during a four-year interval, 2002 at Université Joseph Fourier (Grenoble, France), 2005 at Oklahoma University (where the Biot centennial was celebrated), before BIOT-4 was hosted, in 2009, by Columbia University (New York, USA) where Biot, as the Professor of Mechanics, wrote his seminal 1941 paper on "General theory of three-dimensional consolidation" (Biot 1941), which made him the "Father of Poromechanics."

In 2013, this year marking the 50th anniversary of the death of Karl von Terzaghi (1883-1963), we hold BIOT-5 in memory of this "Grandfather of Poromechanics," the founder of consolidation experiments and theoretical soil mechanics in general. Terzaghi was active as lecturer and consultant all over the world, and he also changed his home base continuously[1], living in

- Austria (born in Prague[2], mechanical engineering studies at Graz University of Technology / TU Graz (1900–1904), internationally active project engineer for the Viennese Pittel construction company (1906–1910), PhD studies at TU Graz (1910–1912), 1914–1916 serving in the Austrian Airforce, together with Richard von Mises and Theodore von Kármán; later, Professor at the Vienna University of Technology / TU Wien from 1929 to 1938),
- Turkey (Professor at the Imperial-Ottoman College from 1916 to 1918, and at the Robert College from 1918 to 1924, in Constantinople/Istanbul),

[1] The following biographical notes largely follow the more detailed presentations of (Brandl 1996) and (de Boer 2000).

[2] at that time, part of the Austro-Hungarian empire

- the United States (Professor at M.I.T. from 1924 to 1929; Professor at Harvard University from 1939 on).

Moving the 2013 edition of the Biot conference series, after two editions in the United States, back to Europe, Vienna therefore appeared as a natural choice. In fact, it is full in Terzaghi's spirit to gather scientists from all over the world to discuss mechanics of porous media in Vienna, where he, from 1929 to 1938, established the, at that time, largest and most comprehensive soil mechanics laboratory in the world at that time, sometimes then the called "Mecca" of soil mechanics. And it is also in Terzaghi's spirit to do so in an expressly transatlantic vision, as he, in 1936, organized the first ever international congress on the topic at Harvard University, and in 1938, promoted the former US President Herbert Hoover, for his merits in economy and engineering, to *Doctor honoris causa* of the Vienna University of Technology. In fact, BIOT-5 is the first major international conference which the Engineering Mechanics Institute (EMI) of the American Society of Civil Engineers (ASCE) co-sponsors outside the United States. Of course, the scope of BIOT-5 goes much beyond soil mechanics *per se*, and again, Vienna appears as one of the first places where intense scientific discussions on what is now called poromechanics took place: Whereas Terzaghi's brilliance lay in combining theoretical considerations with smart macroscopic experimental activities wherever a theoretical understanding seemed out of reach[3], his colleague and opponent Paul Fillunger, Professor for Engineering Mechanics at the Vienna University of Technology, strongly advocated a more "microstructural" viewpoint (Fillunger 1936), proposing equilibrium conditions reminiscent of those finally emerging only in the 1950s as part of the so-called mixture theories (Truesdell and Toupin 1960, Bedford and Drumheller 1983), and most remarkably, Fillunger came up with a proposition on how to "upscale" Poisseuille's law from the pore channel level, to Darcy's law at the level of the porous medium, as well as with a porosity-based pressure partitioning rule between the solid skeleton and the pore fluid, some quarter of a century prior to the conceptually identical stress average rule in continuum micromechanics (Hill 1965, Hashin 1965). Deplorably, rather than contributing with these ideas to a constructive scientific debate, Fillunger chose to present them in the form of a bitter anti-Terzaghi polemic[4], which, in the wake of being condemned in a disciplinary action[5], Fillunger finally remorsefully terminated through suicide in 1937.

Even Fillunger himself was quite aware that the experimental check of his "microstructural" ideas was not feasible at his time—hence, the successful way to further develop the field was in combining Terzaghi's thoughts on solid- and fluid-related force components acting on a piece of porous material, with the foundations of continuum mechanics and thermodynamics: taking this step in his landmark paper (Biot 1941) made Maurice Anthony Biot the true father of experimentally and theoretically sound poromechanics, thus marking the turning point from the Terzaghi-Fillungerian "pre-history" of poromechanics to the official "start" of our scientific discipline. Still, the microstructural approach turned out as conceptually

[3] The most prominent example being the split of the pressure acting on a piece of saturated porous material into a part acting on the solid and another one acting on the pore fluid, and the combination of Darcy's law with an experimentally evidenced empirical relation between the aforementioned overall pressure and the corresponding fluid mass pressed out the sample (von Terzaghi 1923, von Terzaghi and Fröhlich 1936).
[4] This is already evident from the title of his booklet (Fillunger 1936), putting literally Terzaghi's work in question.
[5] which was opened on Terzaghi's request, as to re-install his endangered scientific reputation

strong and convincing; however, it took decades until Nur and Byerlee (1971) and Auriault and Sanchez-Palencia (1977) could give microstructural explanations of Biot's effective stress for poroelasticity, or until de Buhan and Dormieux (1994, 1996) could give a micromechanically sound basis for Terzaghi's effective stress governing the strength properties of (numerous) fluid saturated porous media, or until Auriault and Sanchez-Palencia (1977, Auriault and Lewandowska 1996) came up with fluid flow upscaling laws. All these activities marked the emergence of the field of poro-*micro*mechanics (as documented in Dormieux et al. 2006 and Auriault et al. 2009), which has become a major thread in contemporary research. In addition, the classical continuum approach is being more and more complemented by discrete, molecular, and atomistic approaches (Coussy 2010), striving for ever more integration of material physics into the realm of poromechanics.

These current trends are clearly reflected in the scientific program of BIOT-5. In particular, we are very grateful that a significant number of brilliant scientists were ready to organize mini-symposia on topics that they rated as most interesting and stimulating. These mini-symposia are the natural backbone of BIOT-5's scientific program, their titles and organizer affiliations representing the scientific and geographic breadth of BIOT-5:

MS01: Biot theory in seismic wave propagation
P. Sahay (Center for Scientific Investigation and Higher Education/Centro de Investigación Científica y de Educación Superior—CICESE, Ensenada, Mexico), T.M. Müller (Commonwealth Scientific and Industrial Research Organisation—CSIRO, Earth Science and Resource Engineering, Perth, Australia)

MS02: Mechanics of fluid-infiltrated earth materials - in memory of Terzaghi and Biot
J.R. Rice (Harvard University, Cambridge, MA, USA), F. Lehner (Salzburg University/Universität Salzburg, Austria)

MS03: Application of multi-phase models in structural engineering
G. Hofstetter (Innsbruck University/Universität Innsbruck, Austria), T. Jefferson (Cardiff University, United Kingdom)

MS04: Microporous and mesoporous materials: adsorption and poromechanics
G.W. Scherer (Princeton University, NJ, USA), A.V. Neimark (Rutgers University, New Brunswick/Piscataway, NJ, USA), G. Reichenauer (Bavarian Center for Applied Energy Research/Bayerisches Zentrum für Angewandte Energieforschung—ZAE Bayern/Würzburg University, Germany), G. Pijaudier-Cabot (Pau University/Université de Pau et des Pays de l'Adour, Anglet, France), M. Vandamme (Paris Institute of Technology/École des Ponts ParisTech, Marne-la-Vallée, France)

MS05: Poromechanics of confined reactions
G.W. Scherer (Princeton University, NJ, USA), R. Espinosa-Marzal (Swiss Federal Institute of Technology/Eidgenössische Technische Hochschule—ETH Zurich, Switzerland), D.K. Dysthe (Oslo University/Universitetet i Oslo, Norway), P.B. Kelemen (Columbia University, New York, NY, USA)

MS06: Computational poromechanics
K.K. Muraleetharan (University of Oklahoma, Norman, OK, USA), M. Schanz (Graz University of Technology/Technische Universität Graz—TU Graz, Austria),

V.N. Kaliakin (University of Delaware, Newark, DE, USA)

MS07: From blast and impact responses of porous media to constitutive modeling—Honoring Prof. Frank L. DiMaggio
H. Liu (The City College of New York, NY, USA), H.I. Ling (Columbia University, New York, NY, USA), V.N. Kaliakin (University of Delaware, Newark, DE, USA)

MS09: Multiscale modelling and simulation of granular and porous media
J. Sun (University of Edinburgh, United Kingdom), X. Yin (Colorado School of Mines, Golden, CO, USA)

MS10: The effect of hierarchical pore structure and anisotropy on pore fluid flow in bone tissue
L. Cardoso (The City College of New York, NY, USA), S.C. Cowin (The City College of New York, NY, USA)

MS11: Micro-scale and field-scale modeling of underground storage of wastes and hydrocarbons
M. Ferronato (Padua University/Università degli Studi di Padova, Italy), G. Sciarra (Sapienza University Rome/Sapienza—Università di Roma, Italy)

MS15: Geotechnical engineering—Practical issues of design, construction and applied research
St. Blovsky (Vienna University of Technology/Technische Universität Wien—TU Wien, Austria)

MS16: Coupled processes in geomechanics. Bridging theory and experiments
J.-M. Pereira (Paris Institute of Technology/École des Ponts ParisTech, Marne-la-Vallée, France), E. Romero (Polytechnic University of Catalonia/Universitat Politècnica de Catalunya—UPC, Barcelona, Spain)

MS17: Advance experimental characterization of porous materials
E. Bemer (French Institute of Petroleum/Institut Français du Pétrole—IFP, Energies Nouvelles—New Energies, Rueil-Malmaison, France), F. Skoczylas (Lille Central School/Ecole Centrale de Lille, Villeneuve d'Ascq, France)

MS18: New frontiers in mechanics of cohesive soils
D.R. Katti (North Dakota State University, Fargo, ND, USA)

MS19: Multiscale poromechanics of geomaterials and biomaterials
B. Pichler (Vienna University of Technology/Technische Universität Wien—TU Wien, Austria), A. Giraud (National Higher School for Geology/Ecole Nationale Supérieure de Géologie, Nancy, France), X. Chateau (Paris Institute of Technology/Ecole des Ponts ParisTech, Marne-la-Vallée, France), C. Hellmich (Vienna University of Technology/Technische Universität Wien – TU Wien, Austria)

MS20: Computational geomechanics for deep subsurface injection
S. Yin (University of Wyoming, Laramie, WY, USA)

MS21: Multiscale and stochastic modeling in poromechanics
M. Murad (National Laboratory for Scientific Computing/Laboratório Nacional de Computação Cientifica—LNCC, Petrópolis, Brazil), R.E. Showalter (Oregon State University, Corvallis, OR, USA), X.F. Xu (Stevens Institute of Technology, Hoboken, NJ, USA)

MS22: Multiphysics numerical modelling of geomaterials and computational strategies
F. Pesavento (Padua University/Università degli Studi di Padova, Italy), L. Sanavia (Padua University/Università degli Studi di Padova, Italy), B. Schrefler (Padua University/Università degli Studi di Padova, Italy)

MS23: Soft tissue modelling in bioengineering: from poroelasticity to tissue biophysics
J. Noailly (Institute for Bioengineering of Catalonia, Barcelona, Spain)

MS24: Multiscale modeling of transport phenomena and failure in porous materials
G. Meschke (Ruhr University Bochum/Ruhr-Universität Bochum, Germany), J.J. Timothy (Ruhr University Bochum/Ruhr-Universität Bochum, Germany)

MS25: The applicability of Biot's theory of dynamic poroelasticity to rocks
R.W. Zimmerman (Imperial College, London, United Kingdom)

MS27: Gas shale poromechanics at all scales
Y. Abousleiman (University of Oklahoma, Norman, OK, USA), A. Cheng (University of Mississippi, University, MS, USA), A. Onaisi (Total, France)

MS28: Constitutive modeling of damage and healing in porous media
C. Arson (Georgia Institute of Technology, Atlanta, GA, USA)

Maintaining the tradition of all previous Biot conferences, all scientific contributions are documented in term of full papers making up the following proceedings volume, which in this way becomes the up-to-date 2013 state-of-the-art report on poromechanics, reflecting the ever increasing impact as well as the theoretical, experimental, and practical relevance of the field.

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