HYDRAULIC FRACTURE PROPAGATION THROUGH

GEOLOGICAL DISCONTINUITIES

By

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This thesis is submitted in fulfilment of the requirements for the degree of

Doctor of Philosophy

in the Faculty of Engineering, Computer and Mathematical Sciences

The University of Adelaide

June 2015
Hydraulic fracturing is a stimulation technique widely used to enhance hydrocarbon production and geothermal energy extraction. Other applications include waste disposal and cave inducement and preconditioning of ore for mining. Rocks are naturally fractured and therefore the little-understood problem of hydraulic fracture growth through these pre-existing discontinuities is a key area of research.

Mathematical criteria for predicting whether an induced fracture will cross a discontinuity have been published by several authors. Some used parameters that are difficult to quantify, neglected the stress induced by the hydraulic fracture itself and ignored fluid viscosity effects on crossing behaviour. Others ignored the presence of fluid in the hydraulic fracture, the possibility of fracture re-initiation after slippage and the effect of surface features on crossing. Numerical studies have shown that viscosity-dominated hydraulic fractures would induce slip on the discontinuity more easily than toughness-dominated hydraulic fractures. This implies that crossing should be more difficult for viscosity-dominated hydraulic fractures. To investigate the interaction between hydraulic and natural fractures, laboratory experiments are combined with numerical and analytical work in this thesis to extend two previously published criteria.

This thesis shows the effect of viscosity on the crossing interaction is complex and cannot be predicted based only on whether slip occurs on the discontinuity before the hydraulic fracture intersects it. The laboratory work can also be applied to improved understanding of the effect of the stress field on crossing as it relates to hydraulic fracture height growth. Prediction of the effect of weak bedding planes on height growth has recently gained importance as the risk of vertical growth of fractures into aquifers has emerged as a concern in shale gas and coal seam gas operations. The findings herein can be applied to this problem if the frictional interfaces are considered to represent weak bedding planes. Complete treatment of the height growth problem requires considering fracture growth through elastic layers with contrasts in physical properties.

The experiments show hydraulic fractures may grow to become elliptical because they extend more quickly and further in the direction of maximum stress or in the direction with fewer discontinuities. The preparation of the samples underlined the effect of local imperfections on discontinuities. Small areas of higher or lower contact stress can aid or inhibit fracture initiation. Rock plates must be smooth and flat in order to control this parameter and obtain valid experimental comparisons for contact stress and the other parameters controlling crossing.
Numerical and analytical results are presented as a mathematical expression with universal curves for the locations of slip starting points, providing an important aid for designing industrial hydraulic fractures. One difference between the approach used here and that used by others is their use of the fracture-tip singular stress solution, meaning they do not consider the effect of the non-singular stresses existing around a pressurised fracture. This thesis therefore improves their work.

Experimental and theoretical outcomes herein suggest that hydraulic fracture growth through an orthogonal discontinuity does not depend primarily on the interface friction coefficient. This finding contradicts several models.
ACKNOWLEDGEMENTS

I was welcomed to Australia by CSIRO Energy under the supervision of Dr. Robert Jeffrey to work with the exceptional group he leads. It was here that I learnt so much from his passion and excellence in the field of hydraulic fracturing. I will forever be grateful to Rob for his generosity, understanding, guidance and strong sense of humanity. All these factors motivated me to work towards making this small contribution to such a broad topic.

Prof. Richard Hillis welcomed me to The University of Adelaide. I will always admire his ability to see not only the bigger picture of a problem, but also its solution and applicability. Richard’s high standards and exemplary work ethics, along with his constructive criticism, directness and lessons on effective communication made the experience of working with him very broad. I also thank him for inviting me into the challenging world of geothermal.

Rob and Richard: It was a privilege working with you. Thanks for all the lessons and opportunities you have given me as well for your patience and for believing in me.

Dr. Xi Zhang helped me so much that I consider him my third supervisor. I am very thankful to him for the many lessons on how to find scientific usefulness from almost every result. He was one of the people who most encouraged me to continue when I considered giving up, and I thank him for that. Xi is an inspiring example of perseverance and honesty.

Prof. Emmanuel Detournay and Dr. Andrew Bunger kindly got involved in my project, motivated by their constant interest in the topic of fractures. The elegance of Detournay’s work inspires me as well as the legacy he has left through all his highly competent pupils. I am grateful to Andy for his mentoring, frankness, and taking the time to listen to me when I needed a friend.

My profound gratitude to Prof. Jean-Claude Roegiers from The University of Oklahoma, my first geomechanics instructor. His enthusiasm for applying non-traditional approaches successfully to field situations is an inspiration to me.

Sincere thanks to the external reviewers for their interest in learning about my work. Likewise, my gratitude for your curiosity on this topic to You, the reader. I hope this thesis will provide you with enough insight to inspire you to progress this work.
Acknowledgements

The Hydraulic Fracturing Laboratory at CSIRO Energy is a university in itself. Here I grew not only technically, but also as a person, thanks to the times shared with the experienced technicians who helped me in so many ways. Leo Connelly tops the list, as he was my right-hand man and an unforgettable friend. He, together with his exceptional wife Jennifer, taught me lessons that have improved my nature and spirit. Lessons on precision and elegance, even in dealing with rocks and tools, were passed on to me by Nigel Smith and Anthony Coleman. I extend to them my admiration and respect for their professionalism. Thanks as well to Kevin Quinlan, Michael Camilleri and Greg Lupton for sharing with me their experiences of working at a laboratory. Finally, my gratitude to them all for welcoming me into their families and for teaching me about the Australian culture.

The laboratory work would not have been possible without the financial support of Schlumberger Moscow and CSIRO Energy. My gratitude to them. Special thanks to Dr. Marc Thiercelin (dec.), from Schlumberger, for his understanding. The Endeavour International Postgraduate Research and The University of Adelaide Scholarships represent a grand gesture of generosity and altruism from Australia, which I admire and am grateful for. These two scholarships are administered by a kind and efficient team at the University of Adelaide Graduate Centre. Thanks to all of them as well as to the Petroleum Exploration Society of Australia for awarding me the 2009 Federal Scholarship.

Sincere recognition to the Stress Group at the Australian School of Petroleum especially to Rosalind King and Marie Neubauer for their friendship. Thanks to: Stephen Begg for his support; Noune Melkoumian a thoughtful friend; Richard Daniel for his encouragement; Maureen Sutton for her genuine care; Andy Mitchell, Ian West, Delise Hollands, Eileen Flannery, Themis Carageorgos and the administrative staff for their kind support.

Deep gratitude goes to the staff at Parklands Medical Centre at the University of Adelaide for their support. I will especially keep in my ‘box’ of treasured memories the natural kindness of Dr. Maree White, the interesting challenges suggested by Dr. Jane Vernon-Roberts and the friendly patience of Dr. Brenton Martin. Thanks as well to the Security Escorts of the University of Adelaide for walking with me on so many nights from the Santos Building to their office. The university shuttle was always there, always on time to take the students home. I remember the friendly faces of the drivers of the university shuttle, Andre and Bob. All these great people made my student life much easier.
I was born and raised in Colombia, a country of positivity, passion and dreams. My trips have introduced me to beautiful people who have made a special impact on my life, like: Marco and Rose Cassetta, Gerd Van den Daele, Miroslav Brajanowski, Diana Arbeláez, Gabriela Marinoni, Ximena Crescini, Marcela Moreno, Feisar Joya, Miguel Quintero, Craig Mortimer, Mercedes and Damien Hunt, Mónica Polanco, Erika and Jan Bon, Antonina Mikocka-Walus, Bart Walus, Catherine Leahy, Peter Beilby and Graham Thamm. My gratitude as well to: Lynda Catlow, Greg Rogers, Roz Dunk, Sally Edwards, Kaia Little, Angela Moloney, Hugo Salcedo, Mónica Cleves, Betina Bendall, Jude Marlow, Andrés Vidal, Judith Miller, Andrew Rohde, Yumiko Bonnardeaux, and James Kear. The following families also contributed to the fantastic memories I have: Bon, Bravo, Bunger, Castro, Livore, Marinoni, Oloworaran, Pitaluga, Sandström and Toro. My respect to Angel Bravo (dec.) for the gift of freedom through the practice of valuing the truth.

Immense thanks to ‘my little friends’, all the children that have accompanied me through this journey to remind me that life is to be enjoyed in the simplest way possible. My gratitude to Maria Alejandra Peña for trusting me and becoming an inspiration in my life. Thanks to the advocates for children’s rights like my friend Yoana Walschap and those who I met through the “Amigos de María Alejandra” group, especially Sandra Sarmiento.

I feel very fortunate for the family moments shared, and the bond of love created, with whom I consider my Australian Family. I thank them for the many lessons: my ‘Australian grandmother’ Mrs. Jean Hayman (dec.), on honesty and simplicity; my ‘Viejito’ Mr. Bruce Thamm, on trust and humanity; the Haymans on gratitude and reliability; the Lows on generosity and perseverance; the Aristeguietas on transparency and comradeship; the Connellys on loving life and discipline; the Burkes on listening and acceptance; Marianne Sandström on listening and patience and Drew Breen on true friendship and compassion.

Thanks to my group of soul mates: Onil Ballestas, Isis Dávila, Rania Dughman, Luz Lozano, Janny May, Myrsia Maya, Nohra Muñoz, Saray Torres, Verónica Uribe and Guillermo Obando for their unconditional friendship despite the distance; Mercedes Palacios and Angel Marinoni for sharing their wisdom with me; my incomparable Brice Lecampion for his gentleness; my German sister Carmen Krapf and Mario Werner for their joyfulness; my one and only rowing partner Treena Bron for her support; Amelia and Sean Burke who were there to hug me with the power only children can offer and to their father, Nicholas for his genuine interest in getting to know me which was nurtured by trust.
I had the privilege of growing up with my paternal grandmother Mamá Rosa, who passed away during my PhD studies. This thesis honours her lessons on courage and perseverance and acknowledges the sacrifices she endured in achieving her dream to have an educated family. The influence of my maternal grandmother Ana is evident in the fact that we always do our best, even in chores and in situations that we take for granted.

My siblings and I are constant teachers and students to each other, so to Flavio, Lyra, David, Rocío and Jaime: this achievement of mine is for us all. I cannot forget to send my love to my nieces and nephews, Silvia, Isabella, Alejandra, Paula, Laia, Sebastián and Flavio. Loving acknowledgements to my brother in law John Hincapié for his contagious encouragement and to my sister in law Ophélie Pain for her kindness and understanding.

Finally, but the most important, the unconditional love I have constantly received from my parents Sebastián and Mariela. Despite numerous differences, they always supported myself and my siblings in achieving our dreams. More importantly through their own life experience, they set a constant example of loving what one chooses to do. I always admired my dad’s capacity for redeeming himself after difficult times and my mum’s genuine ability to forgive. These two lessons have been very helpful while doing my PhD. I thank them with a big smile of satisfaction and fulfilment with my life, their lovely gift to me.

I dedicate this thesis to my beloved father, who passed away about one year ago. Dad, I miss you but I am proud of you for having achieved all your dreams. The image of your eyes with its endless love and the energy of your hugs accompany me in the rest of my journey. Infinite thanks for everything you did for me. I love you.

These four pages were the only ones I wrote with my heart, as the thesis had to be written with my brain. However, the underlying basis of it is my passion and love for life, especially my own, so I will dedicate this last paragraph to the thesis itself. I must thank it for being the medium that helped me achieve skills that have made me both a better person and a better professional. I take this opportunity to ask it for forgiveness, as sometimes I denied its beauty and value. For all those days, nights, months and years that witnessed its birth, I humbly toast it with joy and respect. Despite all the life tests I encountered, I finished it and it will always be a nice reminder that it is essential to treasure every single minute lived.

With heartfelt gratitude, Ella María.
Declaration

I certify that this work contains no material which has been accepted for the award of any other degree or diploma in my name, Ella María Llanos Rodríguez, in any university or other tertiary institution and, to the best of my knowledge and belief, contains no material previously published or written by another person, except where due reference has been made in the text.

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Ella María Llanos Rodríguez

4 June 2015
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SELECTED NOMENCLATURE

m: coefficient of friction of the discontinuity

T_o: tensile strength [MPa]

E: Young’s Modulus [GPa]

K: Permeability of the rock [mD]

K_c: Fracture toughness [MPa√m]

Q: Injection rate [ml/s]

T: Fluid temperature [°C]

k: permeability of the natural fracture

K: dimensionless fracture toughness

r: time (s)

r_{mk}: characteristic time (s)

H: distance between closest tip of the hydraulic fracture and the discontinuity

L: distance between furthest tip of the hydraulic fracture and the discontinuity

P_i: internal pressure

Y_s: slip front location

L*: characteristic length

h: evolving non-dimensional parameter

σ_x: horizontal compressive stress acting perpendicular to the interface [MPa]

σ_z: horizontal compressive stress acting parallel to the interface [MPa]

σ_y: vertical compressive stress [MPa]

τ: shear stress

σ_n: normal stress

ϕ: Porosity

ν: Poisson’s ratio

ρ: Density [gm/cm³]

μ: Viscosity [Pa·s]

ω: residual opening of a closed natural fracture

Σ*: characteristic stress