Volume 12, No. 6 August 2001

# CREWES NEWS

**The Consortium for Research in Elastic Wave Exploration Seismology**

## CREWES at San Antonio


CREWES personnel will be in attendance at San Antonio for the SEG Meeting next month, presenting some of our research and manning a booth. While there, we hope to meet as many of our sponsors as possible. We look forward to meeting you and hope that you'll stop by our booth to get the latest news on our current research and forthcoming projects. Our booth is #905 and will be found in the Consortium Area.

We are delighted to have had a number of papers and posters chosen for presentations, and these will be given according to the schedule set out below. See you there! ***CN***

## In This Issue...



## San Antonio 2001: CREWES Presentations Schedule

| Title | Authors | Day | Session | Room |
|---|---|---|---|---|
| *Elastic finite difference modelling in two dimensions: stability and dispersion corrections* | P. M. Manning*<br>G. F. Margrave | Mon. 3.35PM | Modeling I (MOD 1) | 212 |
| *How much does the migration aperture actually contribute to the migration result?* | S. Sun*<br>J. C. Bancroft | Tues. 8:30AM | Migration Problems and Solutions (MIG 4) | 212 |
| *Challenges in imaging shallow high resolution seismic data* | D. C. Henley* | Tues. 9:20AM | Near-surface seismic (NSG 2) | 205 |
| *Finite-difference methods for estimating traveltimes and raypaths in anisotropic media*** | M. A. Perez*<br>J. C. Bancroft | Tues. 9:20AM<br>Wed. 2:20PM<br>Wed. 3:00-5:00PM | Modeling I (MOD P1) | Ballroom A, Exhibit Hall A |
| *The suppression of water-column multiples by wavefield separation and cross-correlation* | Y. Yan*<br>R. J. Brown | Tues. 9:20AM | Multiple Suppression II (MS 2) | 206 |
| *Conversion coefficients at a liquid/ solid interface*** | P. F. Daley* | Tues. 9:45AM<br>Wed. 1:55PM<br>Wed. 2:30-3:30PM | Theory (TH P1) | Ballroom A, Exhibit Hall A |
| *Combining geostatistics and multiattribute transforms: A channel sand case study* | B. H. Russell* et al | Tues. 2:45PM | Case History II (INT 6) | 207 |
| *Simulation of elastic moduli of porous media* | C. P. Ursenbach* | Wed. 9:20AM | Rock Physics I (RP 1) | 212 |

** Presenter    ** Poster Presentation*

(**SEG Schedule** *cont'd next page)*

(**SEG Schedule** *cont'd from previous page)*

| Title | Authors | Day | Session | Room |
|---|---|---|---|---|
| *Dual extrapolation algorithms for Fourier shot record migration* | Y. Mi*<br>G. F. Margrave | Wed. 10:10AM | Prestack Migration Methods I (MIG 5) | 217A |
| *3-C geophone orientation and wave modes polarization* | S.E. Guevara*<br>R.R. Stewart | Wed. 1:30PM | Multicomponent II (MC 2) | 214A |
| *Playing with fire: Noise alignment in trim and residual statics* | C. P. Ursenbach*<br>J. C. Bancroft | Wed. 1:55PM | Noise Levels (SP 6) | 206 |
| *Constrained three parameter AVO inversion and uncertainty analysis* | J. E. Downton*<br>L. R. Lines | Wed. 2:45PM | AVO III (AVO 3) | 213 |
| *Prestack depth imaging from topography with a Fourier method* | Y. Mi*<br>G. F. Margrave | Thurs. 9:20AM | Prestack Migration Methods II (MIG 6) | 217A |
| *Single-well imaging using the full waveform of an acoustic sonic* | L. Chabot* et al | Thurs. 11:00AM | Borehole Seismic III (BH 3) | 217C |
| *Prestack considerations for the migration of oblique reflectors* | J. C. Bancroft*<br>C.P. Ursenbach | Thurs. 11:25AM | AVO IV (AVO 4) | 213 |

** Presenter  ** Poster Presentation*

## Constrained 3-parameter AVO inversion and uncertainty analysis

*Jon Downton*

Amplitude Variation with Offset (AVO) allows one in principle to obtain information on three variables, such as P-impedance, S-impedance, and density. In practice, however, it is generally only feasible to extract two variables. In this work Bayes' theorem is used to derive a 3-parameter non-linear AVO inversion. Geologic constraints based on the available well control or rock physical relationships are incorporated to help stabilize the solution. For the technical details of this AVO inversion see the 2001 SEG abstract under the same title, currently available to sponsors at the CREWES webpage. Subsequent results will be reported at this year's CREWES Sponsors' Meeting. This summary uses a model example and a data example will be used to illustrate the method.

By default, the inversion outputs are the P-impedance, S-impedance and density reflectivity estimates along with uncertainty estimates. Of these, the P-impedance reflectivity is the most reliable, followed by the S-impedance reflectivity and lastly the density reflectivity. Reliability is largely a function of the range of incident angles available for the inversion and the signal-to-noise ratio. To determine geologically reasonable reflectivity estimates, the inversion algorithm weights the constraints based on the above two factors. When the problem is less stable the constraints are weighted more heavily. The ratio of the constrained to unconstrained uncertainty may be used as a quality control to determine the influence of the constraints on the estimate of a particular reflectivity estimate. Only reflectivity estimates that are largely coming from the seismic data should be used in the interpretation to predict the geology

**Model Example.** In order to get a reliable estimate of the density reflectivity we need to have seismic data with good signal-to-noise and large incidence angle range. Figure 1 shows the AVO inversion for the angle range of 0 to 45 degrees, for a synthetic gather with a signal-to-noise ratio of 8. With this large angle range and good S/N to ratio, reliable estimates of the density reflectivity are possible. In this example the density and velocity are uncorrelated. Figure 2 (overleaf) shows the results of the AVO inversion, but on a gather with a signal-to-noise ratio of 1/4. In this case the estimate of the density reflectivity does not correlate well with the actual reflectivity. The estimate is coming primarily from the constraints.

**Data Example.** The inversion so far has been run on 7 different seismic lines. Only one line had sufficient angle range and signal-to-noise to give a geologically significant density reflectivity estimate (Figure 3, overleaf). The zone of interest is the bright spot around 0.72 seconds. Well A is a non-economic gas well which encountered low gas saturations whereas wells C and E encountered economic gas. The porosity and thickness of the sands in all the wells are equivalent. The P-impedance and fluid stack (not shown) give the same response for all the wells. Note that the density section gives a brighter response for the economic gas as expected.

(**AVO Inversion** *cont'd next page)*

(**AVO Inversion** *cont'd from previous page)*

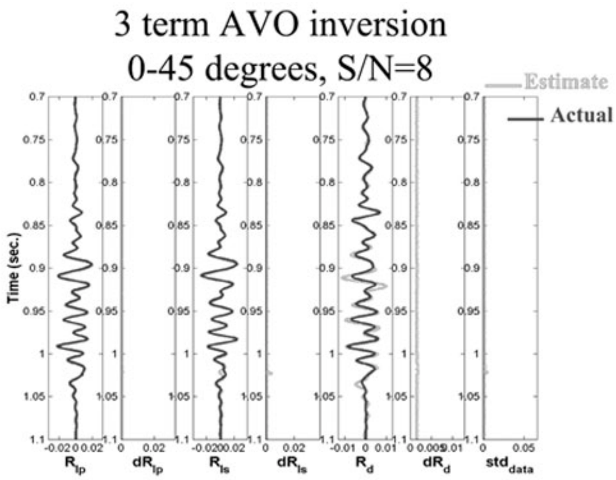


*Figure 1: Results of AVO inversion from 0 to 45 degrees for P-impedance, S-impedance and density reflectivity attributes on a gather with a S/N=8. The estimate is in red and the actual reflectivity in blue. The estimated standard deviation of the P-impedance reflectivity is labeled dRip, S-impedance reflectivity is labeled dRis and density reflectivity is labeled dRd.*

Figure 4 shows the standard deviation and the influence of the constraints on the density reflectivity estimated. Around CDP 2000 the seismic line went through muskeg resulting in poorer quality records. The standard deviation is much larger in this area. Because of the poorer S/N ratio, the constraints are weighted more in the solution. This influence shows in the ratio of constrained to unconstrained uncertainty (Figure 4, bottom panel). However, for most of the zone of interest the solution is largely coming from the data. This combined with the good geologic correlation with the well control suggest the density section is reasonable.

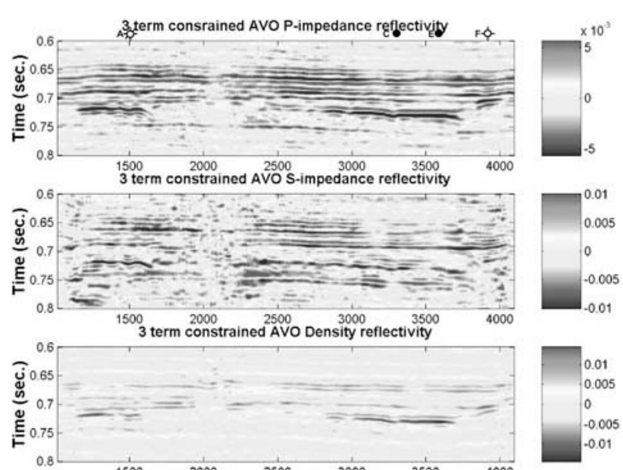


*Figure 3: P-impedance, S-impedance and density reflectivity attribute inversions over producing and non-economic gas fields. Note that it is possible to differentiate on the density section the low gas saturation gas well (Well A) from the economic gas wells (Well C and E).*

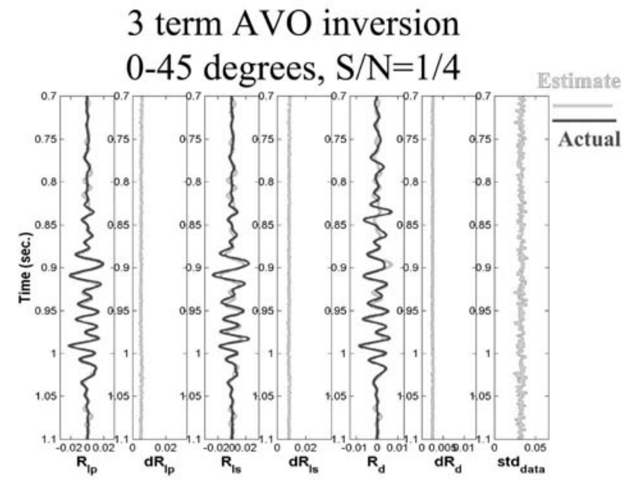


*Figure 2: Results of AVO inversion from 0 to 45 degrees for P-impedance, S-impedance and density reflectivity attributes on a gather with a S/N=1/4. The estimate is in red and the actual reflectivity in blue. The estimated standard deviation of the P-impedance reflectivity is labeled dRip, S-impedance reflectivity is labeled dRis and density reflectivity is labeled dRd.*

Even though most of this article was spent discussing the density reflectivity, this algorithm should be thought of as a general purpose AVO inversion. The same comments about noise and angle range could be made about the stability of the S- and P-impedance reflectivity estimate. There are going to be seismic data sets or portions of datasets where the noise level or angle ranges are insufficient to reliably estimate either the S-impedance or P-impedance reflectivity. By incorporating the quality control displays the interpreter has the tools to understand how significant the AVO inverted results are and act accordingly. ***CN***

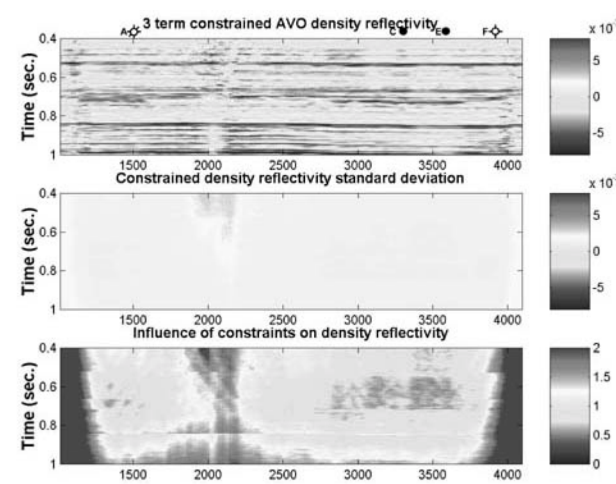


*Figure 4: The density reflectivity and related quality control sections. The standard deviation of the density (middle panel) is considerably smaller than the density reflectivity at the zone of interest. The ratio of the unconstrained to constrained uncertainty (bottom panel) shows the influence of the constraints on the solution. Where this ratio is high, the constraints are dominating the solution. This occurs when the S/N is poor or the range of angles available for the inversion is limited.*

## Suppression of water-column multiples

*Yan Yan*

Recorded wavefields in OBS data can be grouped into downgoing and upgoing wavefields, according to the direction of arrival. These are illustrated in Figure 1. The downgoing wavefield contains the direct wave, receiver-side free-surface multiples and water-column reverberations, while the upgoing wavefield contains the primaries, source-side ghosts and internal multiples. Since the primary reflections are contained only in the upgoing wavefield, extraction of the upgoing wavefield can be used to suppress the downgoing multiples, while still preserving the amplitudes of primary reflections.

Several researchers have worked on wavefield separation (for example Amundsen and Reitan, 1995; Osen et al., 1999; Schalkwijk et al., 1999) and have combined hydrophone and geophone data in different ways to lead to different wavefield-separation formulae for various applications.

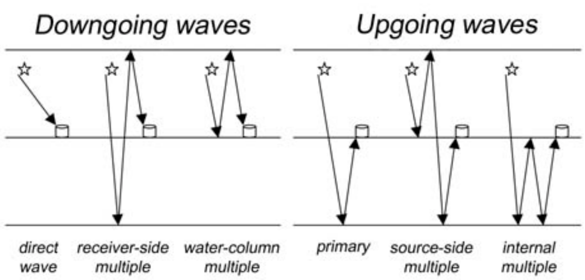


*Figure 1: See text*

The wavefield decomposition procedure, in essence, combines the pressure, horizontal and vertical velocity components in the proper proportions and generates the upgoing P- and S-wavefield. With wavefield separation techniques, the upgoing wavefield, without receiver-side multiples, can be successfully extracted. However, source-side multiple energy remains as part of the upgoing wavefield. In laterally homogeneous cases, source-side multiples will have raypaths that are equivalent in length to those of corresponding receiver-side multiples (see Figure 1), so the two types of multiple are recorded simultaneously. In vertical-geophone data, these two contributions can have similar energies but opposite polarities. We exploit this circumstance to devise a method, based on cross-correlation, to further attenuate the source-side multiple energy.

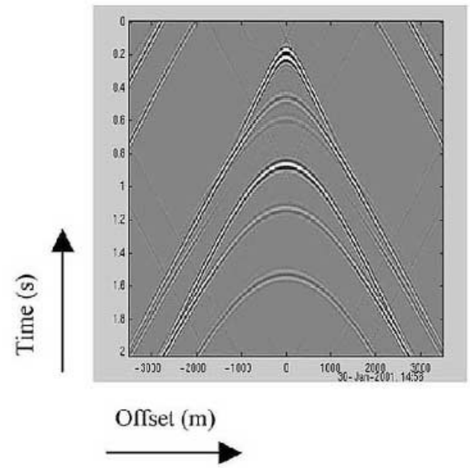


*Figure 2: Total wavefield; synthesized using the Elmo routine (Silawongsawat, CREWES M.Sc. Thesis, 1998) for a model of a water layer above two sediment layers. The source is at the water surface and receivers are on the ocean bottom.*

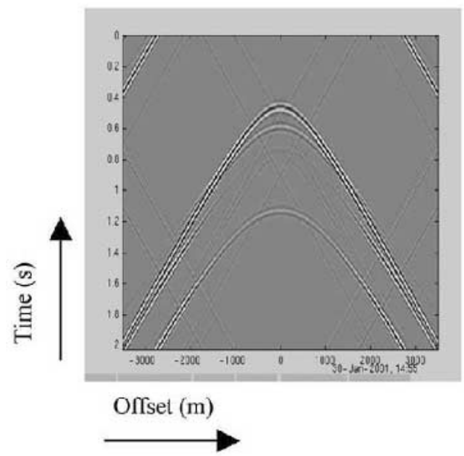


*Figure 3: Upgoing wavefield after application of the wavefield-separation technique.*

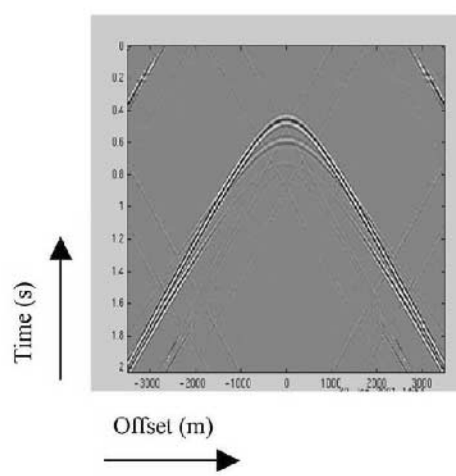


*Figure 4: Upgoing wavefield after application of the cross-correlation method*

(**Suppression** *cont'd next page)*

(**Suppression** *cont'd from previous page)*

Toward this end we cross-correlate the upgoing- and downgoing-wavefield data, U and D, respectively, using, in a moving window, the expression

$$\psi_{UD}(j) = \frac{\sum_{i=1}^{L} U_{i+j} D_i}{\sqrt{\sum_{i=1}^{L} U_{i+j}^2 \sum_{i=1}^{L} D_i^2}}$$

where $\psi_{UD}(j)$ is the cross-correlation of U and D in a particular window for a lag of j samples and L is the length of the window. In view of the identical arrival times (assuming lateral homogeneity) we focus our attention at zero lag. Then the cross-correlation coefficients at samples where the source-side multiples appear should approach -1, depending on how similar the amplitudes are of the upgoing and downgoing contributions to the multiple. Such large negative values can be used as indicators of source-side multiple energy. The indicated sample positions of source-side multiples can in turn be used to eliminate the multiples in the upgoing wavefields of all the components. This procedure is illustrated in Figures 2, 3 and 4.

In summary, the wavefield decomposition technique can be used successfully to suppress the downgoing waves in OBS data. With cross-correlation of up- and downgoing vertical-geophone wavefields, the source-side multiples can be further identified and eliminated. ***CN***

## Synergies in Geophysical, Medical, and Space Imaging

*- the SEG 2001 Summer Research Workshop, as reported by Larry Lines*

The 2001 SEG Summer Research Workshop, held July 22-26 in Newport Beach, California, concerned 'Synergies in Geophysical, Medical, and Space Imaging'. The workshop was chaired by David Lumley of 4th Wave Imaging, attracting 80 scientists from the fields of geophysical, medical, and space imaging. About 50 papers were presented, including many on the latest developments in seismic migration and tomography; the talk by Bob Godfrey of WesternGECO on the state of the art in Ocean Bottom Cable recording was of special interest to those involved in elastic wave imaging.

In addition to the geophysical technologies, it was intriguing to see many of the latest medical imaging developments in computerized tomography (CT) scans and 3-D ultrasound. One of the highlights included a talk on ultrasound imaging by Jeff Resnick, a geophysicist who switched to the medical field. Jeff was able to transcend the "jargon barrier" between fields and describe medical imaging in geophysical terms. His impressive ultrasound images were obtained by the use of "common source prestack Kirchhoff time migration". An example of ultrasound technology is shown in Figure 1, from Resnick's talk showing the face of a fetus after 20 weeks of development. He also showed an image of a beating heart.

Medical images are generally obtained in real time. Ann Scherzinger of the University of Colorado remarked that modern CT scans take less time than it takes the patient to get on and off the table for the scan. There is a transition from film to digital analysis. Medical images are of extremely high quality due to the nature of the experiment and the simplicity of the medium. For example, human bodies show much less variation in acoustical velocity than do the complex rock formations of the earth, making medical imaging an easier problem than its geophysical counterpart.

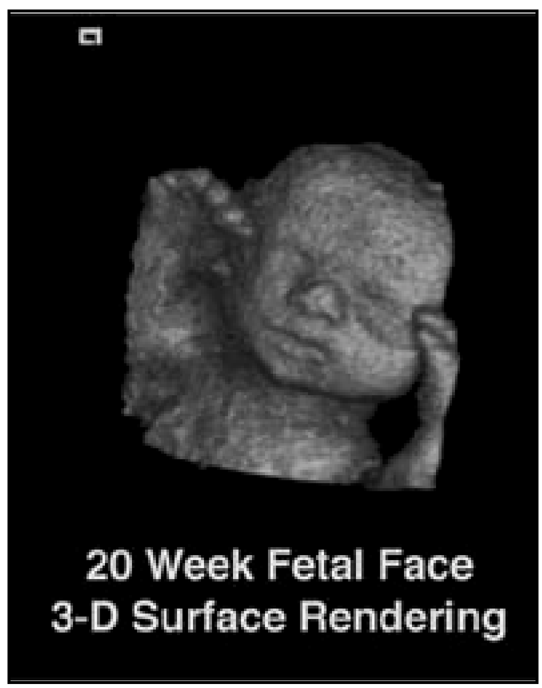


*Figure 1: Courtesy of Jeff Resnick of Acuson, from his talk on "Ultrasound Medical Imaging", as presented at the 2001 SEG Summer Research Workshop.*

(**Synergies** *cont'd next page)*

(**Synergies** *cont'd from previous page)*

Space imaging papers generally focused on the applications of remote sensing and satellite imagery. In the electromagnetic spectrum, these include signals from the visible-near infrared, thermal infrared, and microwave range of spectra. Satellite imagery has many applications in geoscience, engineering and environmental studies, cartography, and military reconaissance. The medium of the atmosphere much simpler than the earth's interior, making satellite data easier to image than in the geophysical case. However, it was felt that geophysicists could benefit from some of the phase unwrapping algorithms used in remote sensing.

What are the synergies that are developing among the various fields? Certainly 3-D visualization methods were useful in all fields. Mathematical methods can be transferred from one field to another. For example, Bob Mager and Norm Bleistein (both applied mathematicians) are working on imaging methods to differentiate between tumors and cysts by using inversion methods developed at the Center for Wave Phenomena. Lawrence Berkeley Laboratory is also using mathematical level set methods in image analysis for medical and geophysical imaging. Certainly time-lapse imaging is another area of common interest for all fields. Parallel multiprocessor computing is an area of common ground.

After attending this workshop, one is left with the question: should geophysicists, in general, and we applied researchers, in particular, be looking at problems in related fields such as medical and space imaging where our algorithms may prove fruitful? Given the common interests and possible synergies in these fields, the answer would appear to be an unqualified "yes". ***CN***

**Reflectivity Explorer Update**

The Reflectivity Explorer, recently added to the CREWES web page, has been expanded for use with converted waves and shear waves. Check it out under the "Interactive Demos" link on www.crewes.org.

Queries and suggestions regarding this utililty can be sent to Chuck Ursenbach at ursenbach@crewes.org.

**Sponsors Meeting 2001**

We would like to remind our sponsors to begin planning for the 2001 CREWES Sponsors Meeting. The dates are 18-20 November.

This year, we are returning to the Delta Lodge at Kananaskis, in the Rocky Mountain foothills.

Watch this space and http://www.crewes.org for further details!

## Course Announcement

Local sponsors may be interested in a graduate-level course being taught this Fall at the University of Calgary. Dr. Rob Stewart will be teaching 'Converted-wave seismic exploration'. Full details can be obtained by contacting Rob at 220-3265 or stewart@crewes.org. ***CN***

**Contact Details**

Readers wishing to contact staff and students should note that all CREWES usernames are attached to the @crewes.org domain.

# Making Contact...

The CREWES Project
Dept. of Geology & Geophysics
University of Calgary
2500 University Dr. N.W.
Calgary, Alberta T2N 1N4
CANADA

**Fax:** (403)284-0074
**Email:** crewesinfo@crewes.org
**WWW**: www.crewes.org

**Directors**:
Dr. Robert Stewart: stewart
Dr. Gary Margrave: gary
Dr. Don Lawton: donl
Dr. Larry Lines: lines

**Associated Faculty Members:**
Dr. John Bancroft: bancroft
Dr. Larry Bentley: bentley
Dr. Jim Brown: jbrown
Dr. Rudi Meyer: meyer

**Administrative Manager**:
Louise Forgues: louise

**Research Staff**:
Henry Bland: henry
Dr. Pat Daley: daley
Eric Gallant: eric
Kevin Hall: khall
Dave Henley: henley
Mark Kirtland: kirtland
Han-Xing Lu: lu
Dr. C. Ursenbach: ursenbach

**Graduate Students**:
Jeff Beckett: beckett
Louis Chabot: chabot
Jon Downton: downton
Pavan Elapavuluri: pavan
Jeff Grossman: grossman
Victor Iliescu: iliescu
Peter Manning: manning
Michael Mazur: mazur
Yanpeng Mi: mi
Carlos Nieto: nieto
Shauna Oppert: oppert
Marco Perez: perez
Brian Russell: russell
C. Silawongsawat: pensil
Shuang Sun: shuang
Alexandru Vant: vant
Ian Watson: watson
Yan Yan: yyan
Jianli Yang: yang
Hongbo Zhang: hzhang
Jianlin Zhang: zhang
Ye Zheng: ye
Ying Zou: zou