BULLETIN

Corpus Christi Geological Society

and

Coastal Bend Geophysical Society

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Table of Contents

Officers, Committees and Chairpersons for CCGS/CBGS………………………………………………. 2&3

CCGS/CBGS Joint Calendar of Meetings & Events…………………………………………………… 4&5

CCGS President's Letter………………………………………………………………………………………. 6

Membership Renewal 2019-20……………………………………………………………………………. 7

CBGS President's Letter………………………………………………………………………………………. 8-11

Society Kickoff Bar-B-Q announcement………………………………………………………………. 12

Memorial Barnard Dietz……………………………………………………………………………………. 14

Annual CCGS Fishing Tournament……………………………………………………………………... 16,17

Volcanic history of the lmbrium basin: A close-up view from the lunar rover Yutu……….. 19

CCGS Papers available for purchase at the Bureau of Economic Geology……………………. 33

Geo Link Post…………………………………………………………………………………………………… 34

Type Logs of South Texas Fields…………………………………………………………………………. 35

Order Oil Men DVD…………………………………………………………………………………………… 36

Wooden Rigs Iron Men……………………………………………………………………………………… 37

Professional Directory………………………………………………………………………………………. 38

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2019-2020
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2017-2018

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Visit the geological web site at www.ccgeo.org

CCGS/CBGS JOINT MEETING SCHEDULE 2019-2020

September 2019

S	M	T	W	Th	F	S
1	2	3	4	5	6	7
8	9	10	11	12	13	14
15	16	17	18	19	20	21
22	23	24	25	26	27	28
29	30					

October 2019

S	M	T	W	Th	F	S
		1	2	3	4	5
6	7	8	9	10	11	12
13	14	15	16	17	18	19
20	21	22	23	24	25	26
27	28	29	30	31		

November 2019

S	M	T	W	Th	F	S
					1	2
3	4	5	6	7	8	9
10	11	12	13	14	15	16
17	18	19	20	21	22	23
24	25	26	27	28	29	30

Thursday, Sept. 26th at 5:30-8:00p.m. Kickoff at Hoegemeyer's Barbeque Barn.

11:30-l:00 pm
Speaker: Dr. Neil Bockoven

December 2019

S	M	T	W	Th	F	S
1	2	3	4	5	6	7
8	9	10	11	12	13	14
15	16	17	18	19	20	21
22	23	24	25	26	27	28
29	30	31				

January 2020

S	M	T	W	Th	F	S
			1	2	3	4
5	6	7	8	9	10	11
12	13	14	15	16	17	18
19	20	21	22	23	24	25
26	27	28	29	30	31	

February 2020

S	M	T	W	Th	F	S
						1
2	3	4	5	6	7	8
9	10	11	12	13	14	15
16	17	18	19	20	21	22
23	24	25	26	27	28	29

CCGS/CBGS Joint Meeting Schedule 2019-2020

			March			
S	M	T	W	Th	F	S
			2020			
1	2	3	4	5	6	7
8	9	10	11	12	13	14
15	16	17	18	19	20	21
22	23	24	25	26	27	28
29	30	31				

			April			
S	M	T	W	Th	F	S
			2020			
			1	2	3	4
5	6	7	8	9	10	11
12	13	14	15	16	17	18
19	20	21	22	23	24	25
26	27	28	29	30		

			May			
S	M	T	W	Th	F	S
			2020			
					1	2
3	4	5	6	7	8	9
10	11	12	13	14	15	16
17	18	19	20	21	22	23
24	25	26	27	28	29	30
31						

Calendar of Meetings and Events

Calendar of Area Monthly Meetings

Corpus Christi Geological/Geophysical Society... Third Wed.—11:30a.m.
SIPES Corpus Christi Luncheons.. Last Tues.—11:30a.m.
South Texas Geological Society Luncheons.. Second Wed—noon San Antonio
San Antonio Geophysical Society Meetings... Fourth Tuesday
Austin Geological Society... First Monday
Houston Geological Society Luncheons... Last Wednesday
Central Texas Section of Society of Mining, Metallurgy & Exp............................... 2nd Tues every other month in San Antonio

CCGS PRESIDENT'S LETTER

Welcome to the 2019/2020 season of our illustrious society. We have some changes this year to the luncheon schedule; only four typical luncheons, and two technical sessions courtesy of the CBGS. Our BBQ kickoff will be held at Hoegemeyer's Barbeque Barn on Thursday September 26, 2019 at 5:30pm to 8:00pm. Our regular luncheons will be held in November 20th, January 15th, April 15th and May20th. The two technical sessions will be held in October and February.

Our fishing tournament this year was a big success, raising over $2000.00 for the scholarship fund. Over the years we have donated $55,000 to the CCGS scholarship fund.

Thank you to our current board, Randy Bissel, Vice President; Sebastian Wiedmann, treasurer; Emily Olson, Secretary; BJ Thompson, Counselor; Rick Paige, Counselor. As always, we need more volunteers. A special thank you to Emily Olson for stepping up, and Brianna Watkins for offering to manage our social media foot print.

Looking forward to a great year.

Austin Nye—VP Exploration & Land
CCGS President

RENEW…RENEW…RENEW…RENEW…RENEW…RENEW…RENEW…RENEW

Please RENEW for the 2019-20 Membership Period using those handy forms we mailed in August.

Everyone should have received their **2019-2020** Membership Renewal forms in the US Mail.

- **PRINTED BULLETINS** are available to any member for $60/year. We must have a valid mailing address. Please confirm your mailing address on the renewal form.
- **Emails! Please legibly re-write your preferred email address at the bottom of the form.** We are striving to maintain **100%** of the Society reachable by email. Your email is vital if you've chosen not to receive the printed Bulletin.
- **Please return the form promptly**…yes, before (or at) the Kickoff party on September 26. Return of your form is *vital* to keeping our records in order, that's why we enclose a return envelope.
- **IMPORTANT:** Even if you plan to pay at the Kickoff, **please bring your renewal form and payment in the envelope!** Honorary and student members, please return your forms, too! Students need to update emails, employment, and contact info.
- **PAY ONLINE** at **www.ccgeo.org** and follow the simple steps. We ask that you still return corrected member information via the enclosed envelope…or email it to membership@ccgeo.org…or fax it to us at 361-885-0120.

USE THIS WEIRD LOOKING THING WITH YOUR SMARTPHONE>>>>>>>>>>>>>>>>>

We mailed over 200 **renewals** this year and it is very expensive for our Societies. Your prompt return of your renewal form is *your* part of this process. Please make this effort worthwhile for our Society.

RENEW…RENEW…RENEW…RENEW…RENEW…RENEW…RENEW…RENEW

For new members, active or student. Email **randyb@headingtonenergy.com** to get a membership form. Just print it, fill it out and send it along with your check (no fee for students) to: CCGS Membership, 500 North Shoreline Blvd., Ste. 902N, Corpus Christi, Texas 78401-0343. Contact Randy Bissell at **randyb@headington.com** or **(361) 885-0110** with any questions. Thanks for your quick response – earlier makes it much easier! And remember:

RENEW…RENEW…RENEW…RENEW…RENEW…RENEW…RENEW…RENEW

CBGS President's Letter

CBGS Board 2019-2020

Dr. Subbarao Yelisetti- President
Samara Omar- Vice President
Erik Scott- Secretary/ Treasurer
Matt Hammer - Scholarship Chair
Mark Wiley - Golf Chair
Education – Robert Schneider

CBGS Scholarships

The board awarded three scholarships of $2,000 each to undergraduate geophysics majors from Texas A&M University-College Station, University of Houston and Texas A&M University-Kingsville in 2017-2018. We will be awarding the scholarships again this year.

Scholarship Requirements

Criteria for awarding the Scholarship from Coastal Bend Geophysical Society of Corpus Christi, Texas:

1. Scholarships are open to undergraduate or graduate students.
2. Must have declared major in Geophysics, or Geology with a concentration in Geophysics or Petrophysics.
3. Preference is given to students attending Coastal Bend schools (TAMU-K, TAMU-CC and Del Mar College), then to Coastal Bend natives attending other universities.
4. Must have a GPA of at least 3.0 and be in good standing with the school.
5. Must make effort to attend a Coastal Bend Geophysical Society Meeting in Corpus Christi Texas after being awarded a scholarship to be recognized by the society.

News

- According to the U.S. Energy Information Administration (EIA) projections, the U.S. oil production would rise to 12.27 million bpd in 2019 from a record 10.99 million bpd in 2018.
- According to EIA projections, U.S. crude output would rise by 85,000 barrels per day (bpd) in September to a record 8.77 million bpd.
- At the time of writing this report, U.S. crude futures were trading around $54 a barrel for the balance of 2019 and $52 in calendar 2020 as reported by Scott DiSavino on reuters.com.

- The U.S. active rig count so far this year has averaged 1,004.
- According to the analysts at Simmons & Co forecast, the average combined oil and gas rig count will slide from a four-year high of 1,032 in 2018 to 970 in 2019 and 955 in 2020 before rising to 997 in 2021 as reported by Scott DiSavino on reuters.com.

CBGS Business

CBGS currently has 52 active members, 4 honorary members, and 60 student members.

CBGS workshops/talks

- As part of the annual Kickoff Bar-B-Q, CBGS hosted Dr. Satinder Chopra on Sep 19, 2018 at the EOG conference center. His talk was entitled "Seismic reservoir characterization of Utica-Point Pleasant shale with efforts at quantitative interpretation – a case study".
- CBGS offered a land seismic acquisition workshop on Dec 5th in EOG conference center with the following talks.

Talks:

1. A Brief Introduction to Seismic Acquisition (Students & New Professionals Encouraged) by Lonnie Blake, EOG
2. A Comparison of Long, Short, and Slip Sweep 3D Data Image Volumes Acquired And Constrained By Equivalent Source Time (KWP Phase I) by J. W. (Tom) Thomas, Kevin Werth, Tom Phillips, Chris Lindsey Dawson Geophysical Co.
3. A Comparison of 3D Multi-Component (9C) Data Image Volumes Acquired With Conventional and Simultaneous Source Techniques Also With Adequate Spatial Resolution For Compressive Sensing Investigation (KWP Phase 2) by J. W. (Tom) Thomas, Kevin Werth, Tom Phillips, Chris Lindsey Dawson Geophysical Co.
4. SAExporation - More, Recent Advances in Onshore Seismic Data Acquisition Methods by Howard Watt, SAExporation, Houston

CBGS is looking forward to offer many such workshops in the future. Topic/speaker suggestions are welcome. Email your suggestions to Samara_Omar@eogresources.com or Subbarao.Yelisetti@tamuk.edu

Golf Tournament

CBGS organized its annual **Golf Tournament** to fund its scholarship program in the first week of October, 2018 at Northshore Country Club. Raised ~$4,000 for the scholarship fund.
If you are interested in our next Golf Tournament, please contact Mark Wiley at Mark_Wiley@eogresources.com

New Degree Tracks at TAMUK

- Texas A&M University-Kingsville (TAMUK) started its first cohort of MS Petrophysics program in Fall 2018. If you are interested in joining this program in Fall 2019, please contact the graduate coordinator for MS in Petrophysics, Dr. Subbarao Yelisetti at Subbarao.Yelisetti@tamuk.edu.
- **BS degree in Geophysics, Minor in Geophysics and Certification in Geophysics** offered at Texas A&M University-Kingsville since Fall 2017. Interested students can contact Dr. Subbarao Yelisetti (Subbarao.Yelisetti@tamuk.edu) for additional information.

Exploration Geophysics and Borehole Geophysics classes

PHYS 5382 Exploration Geophysics and **PHYS 5388 Borehole Geophysics** classes are offered in Fall 2019 at Texas A&M University-Kingsville. This is available for the professional community as well as our students. You can sign up as a "transient" student in order to take classes without actually enrolling in the school. If anyone in the professional community wishes to sign up for this, please contact, Dr. Subbarao Yelisetti Subbarao.Yelisetti@tamuk.edu.

SEG Distinguished Lecture

CBGS and TAMUK SEG student chapter organized 2018 SEG Distinguished Lecture in January, 2018. We wish to organize many more lectures in the future.

Education/Events

-SEG

SEG 2019 annual meeting will be held in San Antonio, TX from Sep 15-20th. Abstract deadline is April 1, 2019. See https://seg.org/Annual-Meeting-2019 for additional details.

See https://seg.org/Education/Lectures/Distinguished-Lectures for information about upcoming SEG distinguished lecture in Houston and other locations.

See https://seg.org/Education/Lectures/Honorary-Lectures for SEG honorary lecture locations in Texas.

-AGU

2019 Fall AGU annual meeting will be held in San Francisco, CA from December 9-13th, 2019.
https://fallmeeting.agu.org/2018/future-meetings/

-GSA

The Geological Society of America's 131st annual meeting will be held in Phoenix, AZ from 22-25th September 2019.
http://www.geosociety.org/GSA/Events/Annual_Meeting/GSA/Events/gsa2019.aspx

Monthly Saying

"Striking oil would seem to be rather an easy process on such grounds. It would be worth trying" - Malcolm Mcleod (1872) commenting on the journal of Chief Factor Archibald McDonald written in 1828 in reference to the Bituminous Springs along the Athabasca River.

Monthly Summary

Texas Oil and Gas Info	Current Month	Last Month	Difference	
Texas Production	**MMBO/BCF**	**MMBO/BCF**	**MMBO/BCF**	
Oil	125.7	134.6	-8.9	April
Condensate	15.4	15.3	0.1	April
Gas	743.9	773.4	-29.5	April
	Current Month	**Yr to date - 2019**	**Yr to date - 2018**	
Texas Drilling Permits	912	7166	8330	July
Oil wells	212	1746	2160	July
Gas wells	58	436	519	July
Oil and Gas wells	537	4416	5075	July
Other	9	69	80	July
Total Completions	699	5749	6514	July
Oil Completions	499	4278	5089	July
Gas Completions	156	1181	1084	July
New Field Discoveries	0	7	15	July
Other	2	18	24	July

Subbarao Yelisetti
President, CBGS

The Corpus Christi Geological Society
The Coastal Bend Geophysical Society

Invite you to the

Society Kickoff Bar-B-Q

Thursday, September 26, 2019
5:30 to 8:00 p.m.

Hoegemeyer's Barbeque Barn

711 Concrete Street (Located across from Concrete Street Amphitheater).
From downtown, take Chaparral St. north, then left on Belden St.

$25 per member/guest
$15 students

Complimentary Bar Courtesy of

GISLER BROTHERS LOGGING CO., INC.

South Texas Operations
P.O. BOX 485 RUNGE, TEXAS 78151
Office : (830) 239-4651 Cell : 361-676-1369

West Texas Operations
P.O. BOX 1759 STANTON, TEXAS 79782
Office : (432) 270-7730 Cell: 361-676-1369

RSVP (required) by Monday, Sept. 23

Dorothy Jordan, Dorothy@headingtonenergy.com, 361-885-0113

Wes Gisler, wes@gislerbrotherslogging.com, 1-830-239-4651

SPONSORS

Memorial
Barnard Dietz

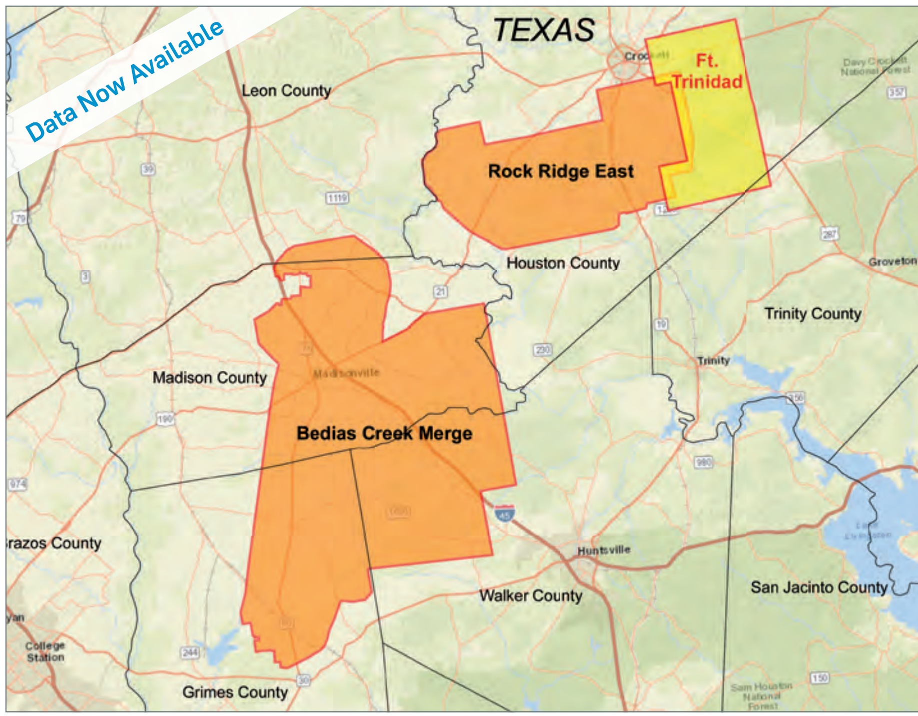
Upon hearing that Barnard Dietz had passed, I found myself thinking back as to when I first became acquainted with him. In 1966 I came to work for Texas Oil & Gas as an engineer in Corpus Christi. Barnard was the Gulf Coast District Geologist for TXO. The next year he was promoted to Chief Geologist, assigned to the corporate office in Dallas. All major geological prospects had to receive his blessing prior to proceeding further in the planning stage. Presenting a Gulf Coast prospect to Barnard was sometimes an uncomfortable job. He already had strong opinions about the geology and was very outspoken, and rightfully so. One main thing I admired about him was even though some discussions could become very heated at times, he never seemed to hold a grudge. Another thing I admired was that every time we spoke, he would always offer me a word of encouragement. He was definitely a team player.

One major parameter defining the success of an individual, is whether or not they lived their life in such a way as to make a positive impact on those they had contact with. Barnard Dietz did that. I'm very honored to have been a friend and a colleague of his. May he rest in peace.

Louis Little

YOU'VE ARRIVED

New Ft. Trinidad 3D Survey
Houston and Trinity Counties, TX



CGG continues to expand its East Texas footprint with high-quality 3D projects while illuminating the stacked pay formations.

Data is already available from our Bedias Creek Merge and Rock Ridge East projects. Orthorhombic PSTM from our newest project Ft. Trinidad is also now available.

The right data, in the right place, at the right time

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CGG
Passion for Geoscience

Annual CCGS Fishing Tournament

The 10th Annual CCGS Fishing Tournament was a huge success. The festivities started Thursday evening with the Dock Party/Captain's Meeting at Treasure Island Bar in beautiful Port Aransas, Texas. Saltwater Grill provided some great food followed by the Captain's Meeting and door prize giveaway. Thank you to all the volunteers who made our Thursday event run so smoothly.

Eighteen inshore teams set out Friday morning under perfect conditions, and brought back some really impressive fish. We had a very competitive group of anglers making the afternoon weigh-in a great experience. Thanks to Pete Graham and Schlumberger for the fajitas on Friday.

The last 10 years have been a great experience for all of us involved in putting this tournament together. With the help of our tremendous sponsors, most of which have been with us from day one, our winners took home over $15,000.00 in cash and prizes. To date we have donated over $55,000.00 to support the CCGS Scholarship Trust Fund and various other continuing education funds. I look forward to the coming years and hope we can continue to put on a successful industry event.

Leighton Devine
Fishing Tournament Chairman

Kelby Broussard (TEXEGY)

David Musgrove
(TEXLA Energy Management)

Zach Corcoran (Sir Drake Oil & Gas Company)

SPONSORS

Volcanic history of the Imbrium basin: A close-up view from the lunar rover Yutu

Jinhai Zhang[a], Wei Yang[a], Sen Hu[a], Yangting Lin[a,1], Guangyou Fang[b], Chunlai Li[c], Wenxi Peng[d], Sanyuan Zhu[e], Zhiping He[f], Bin Zhou[b], Hongyu Lin[g], Jianfeng Yang[h], Enhai Liu[i], Yuchen Xu[a], Jianyu Wang[f], Zhenxing Yao[a], Yongliao Zou[c], Jun Yan[c], and Ziyuan Ouyang[j]

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Edited by Mark H. Thiemens, University of California, San Diego, La Jolla, CA, and approved March 24, 2015 (received for review February 13, 2015)

We report the surface exploration by the lunar rover Yutu that landed on the young lava flow in the northeastern part of the Mare Imbrium, which is the largest basin on the nearside of the Moon and is filled with several basalt units estimated to date from 3.5 to 2.0 Ga. The onboard lunar penetrating radar conducted a 114-m-long profile, which measured a thickness of ∼5 m of the lunar regolith layer and detected three underlying basalt units at depths of 195, 215, and 345 m. The radar measurements suggest underestimation of the global lunar regolith thickness by other methods and reveal a vast volume of the last volcano eruption. The in situ spectral reflectance and elemental analysis of the lunar soil at the landing site suggest that the young basalt could be derived from an ilmenite-rich mantle reservoir and then assimilated by 10–20% of the last residual melt of the lunar magma ocean.

volcanic history | Imbrium basin | lunar rover Yutu | lunar penetrating radar | Chang'e-3 mission

The surface of the Moon is covered by regolith, a mixed layer of fine-grained lunar soil and ejecta deposits, which is crucial to understanding the global composition of the Moon. The lunar regolith has also recorded the complex history of the surface processes, and it is the main reservoir of ^{3}He and other solar wind gases. The thickness of the lunar regolith was estimated to be from 2 to 8 m in the maria and up to 8–16 m in the highland areas using various methods (1), including crater morphology (2, 3), seismology with low spatial resolution (4), radar wave scattering (5), and microwave brightness temperature (6). However, no in situ measurement of spectral reflectance, elemental compositions, lunar regolith thickness, or subsurface structures has been carried out.

The surface of the Moon is dominated with numerous large basins. They were formed about 3.9 Ga (7, 8), probably by the late heavy bombardment, and then filled with dark lava flows derived from partial melting of the lunar mantle, within a period mainly during 3.8–3.1 Ga (7). The Imbrium basin is the largest and was formed on Procellarum KREEP [potassium (K), rare earth elements (REE), and phosphorus (P)] Terrane (9), a unique terrain highly enriched in U, Th, and K radionuclides and other incompatible trace elements referred to as KREEP (10) and considered as the last residual melt of the Lunar Magma Ocean (11). The presence of the KREEPy materials, indicated by high concentrations of radionuclides U, Th, and K (9), around the rims of the Imbrium basin suggests that they are likely the basin-forming ejecta deposits. At least three main lava flows, dated from 3.5 Ga to 2.0–2.3 Ga (7, 12), have been recognized in Mare Imbrium with distinct FeO and TiO_2 concentrations (13, 14), which brought up interior information of this KREEP-rich terrain. The old and low-Ti basalt unit has been sampled by the Apollo 15 mission that landed at the eastern rim of the Imbrium basin. Information of other lava flows in Mare Imbrium was obtained only by remote sensing from orbit. On December 14, 2013, Chang'e-3 successfully landed on the young and high-Ti lava flow in the northeastern Mare Imbrium, about 10 km south from the old low-Ti basalt unit (Fig. 1).

The lunar rover Yutu (named for the jade rabbit on the Moon in a Chinese fairy tale) was equipped with an active particle-induced X-ray spectrometer (APXS), a visible to near-infrared (450–945 nm) imaging spectrometer and short-wave infrared (900–2,395 nm) spectrometer (VNIS), and a lunar penetrating radar (LPR), accompanied by a stereo camera and a navigating camera. Originally, the mission planned to have the lunar rover measure chemical and mineral compositions of the lunar soil and various types of ejecta rocks and to carry out a LPR profile of the lunar regolith and subsurface structures in the first 3 mo. The mission was scheduled to extend up to 1 y and to explore the old low-Ti lava flow ∼10 km north. Unfortunately, some of Yutu's mechanical parts failed to move just before the rover prepared for sleeping at the end of the second month due to unknown faults probably in the control system. During the first 2 mo, Yutu successfully carried out two APXS and four VNIS analyses of the lunar soil and performed a 114-m-long LPR profile along the rover track in the landing area (Fig. 2). These in situ measurements

Significance

After the Apollo and Luna missions, which were flown about 40 years ago, the Moon was explored only from orbit. In addition, no samples were returned from the young and high-FeO and TiO_2 mare basalt in the northern Imbrium basin. Such samples are important to understand the formation and evolution of the Procellarum KREEP [potassium (K), rare earth elements (REE), and phosphorus (P)] terrain, a key terrain highly enriched in radioactive nuclides. The Chang'e-3 mission carried out the first in situ analyses of chemical and mineral compositions of the lunar soil and ground-based measurements of the lunar regolith and the underlying basalt units at this specific site. The lunar regolith layer recorded the surface processes of the Moon, whereas the basalt units recorded the volcanic eruption history.

Author contributions: Y.L., C.L., Y.Z., J. Yan, and Z.O. designed research; J.Z., W.Y., S.H., Y.L., and W.P. performed research; G.F., W.P., Z.H., H.L., J. Yang, E.L., and J.W. contributed new reagents/analytic tools; J.Z., W.Y., S.H., Y.L., S.Z., B.Z., Y.X., and Z.Y. analyzed data; and J.Z., W.Y., S.H., Y.L., and Y.X. wrote the paper.

The authors declare no conflict of interest.

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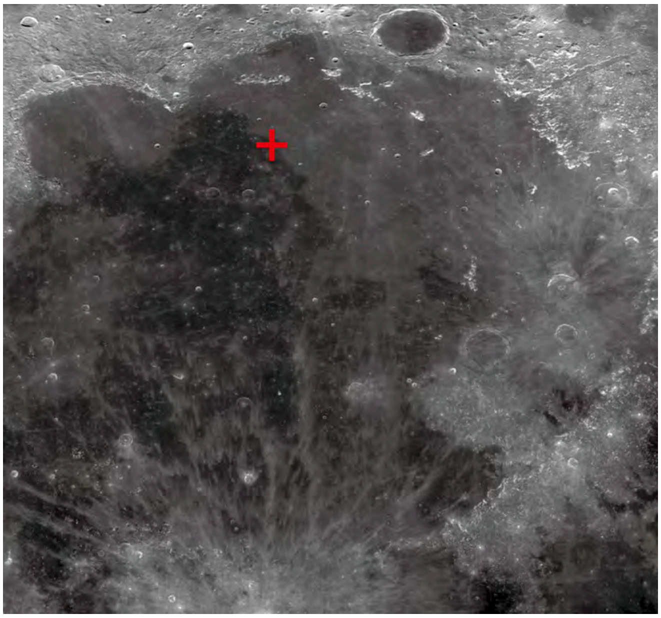

Fig. 1. The landing site of Chang'e-3 (red cross), on the high-Ti basalt (dark gray) near the boundary in contact with the low-Ti basalt (light gray). The background image was taken by Chang'e-1.

provide insights into the volcanic history of Mare Imbrium and the ground-truth data for calibration of the orbital data.

Chemical Compositions

The chemical compositions of the lunar soil have been measured with the onboard APXS equipped on the robotic arm (Table 1), and detailed data processing is given in *SI Appendix*. The X-ray spectra of the lunar soil were emitted from the surface within a diameter of 6 cm, displaying clear peaks of Mg, Al, Si, Ca, Ti, K, Cr, Fe, Sr, and Zr and detection of Y and Nb (*SI Appendix*, Fig. S3). The quantitative compositions of the lunar soil were calibrated with 10 working references covering the compositional ranges of the lunar soil, after correction for background, peak overlapping, and decay of the ^{55}Fe and ^{109}Cd sources. The two analyses, carried out in different locations, are nearly identical to each other within the analytical uncertainties, confirming the analytical reproducibility. The lunar soil contains higher TiO_2 (4.0–4.3 wt %) and FeO (21.3–22.1 wt %) but lower Al_2O_3 (10.5–11.5 wt %) compared with the Apollo and Luna soil samples (*SI Appendix*, Fig. S6). The composition of the lunar soil could represent that of the basalt beneath, suggested by its high FeO and TiO_2 contents. This is confirmed by the compositional mapping of the rims and proximal ejecta of small impacts (0.4–4 km in diameter) on the same high-Ti basalt unit, which show the upper limits of 20 wt % FeO and 4–7 wt % TiO_2 (14). The intermediate concentration of TiO_2, compared with the gap between 4 and 7 wt % TiO_2 for Apollo and Luna mare basalts (15) (Fig. 3), probably indicates a distinct type of mare basalt. Based on the correlation between K and Th (16), 4 ppm Th of the lunar soil was estimated, which is slightly higher than the remote sensing value (~2 ppm Th) in Mare Imbrium (17). The incompatible lithophile trace elements Zr, Y, and Nb are enriched by factors of 0.10–0.12, 0.11–0.18, and 0.17 relative to the referred composition of KREEP (10), respectively. In addition, the concentration of K is 0.18–0.22 × KREEP. Such a nearly flat KREEP-normalized pattern of the lunar soil suggests that these incompatible lithophile trace elements can be attributed to assimilation of 10–20% of KREEP component. A scenario is that the basalt was derived via partial melting of ilmenite-rich mantle reservoir and then contaminated by the residual KREEP layer beneath the ferroan anorthosite crust as it ascended to the surface. Alternatively, the basalt was formed via partial melting of a mantle reservoir that had mixed with sinking dense ilmenite-rich KREEPy rock.

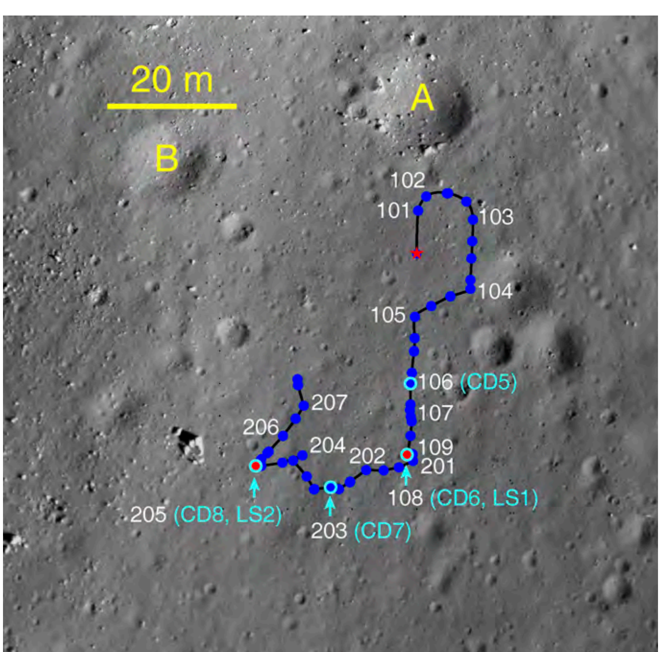

Fig. 2. Chang'e-3 landing site and the rover Yutu's track. Crater A is blocky, indicating penetration through the regolith. Crater B is the largest one without blocks in the landing area. The APXS (LS1–LS2) and VNIS (CD5–CD8) analysis positions and the rover navigation points are marked. The image was composed from the series images taken by the Chang'e-3 landing camera.

Mineral Abundances and Optical Maturity Index

Four reflection spectra of the lunar soil have been acquired with the onboard VNIS, and the data processing is given in *SI Appendix*. The calibrated spectra are similar to the laboratory measurements of Apollo mare soil samples, showing absorption at 1 μm and 2 μm responding to the presence of pyroxene and plagioclase (*SI Appendix*, Fig. S11). The decoded average mineral composition of the soil is 17.9 vol % pyroxene (13.0–20.6 vol %) and 16.4 vol % plagioclase (15.0–17.5 vol %). This mineral composition

Table 1. Chemical compositions of the lunar soil measured with APXS

Sample name	LS1	±	LS2	±
SiO_2	42.8		43.2	
MgO	9.9	1.5	8.9	1.9
Al_2O_3	11.5	0.9	10.5	1.0
K_2O	0.18	0.01	0.15	0.01
CaO	10.4	0.3	10.9	0.4
TiO_2	4.0	0.2	4.3	0.2
FeO	21.3	1.7	22.1	1.9
Total	100.0		100.0	
Cr, ppm	877	162	825	161
Sr, ppm	139	19	198	29
Y, ppm	34	10	54	13
Zr, ppm	200	26	168	49
Nb, ppm	13	2	14	10

In wt %, normalized to 100 wt %. LS1, lunar soil 1; LS2, lunar soil 2.

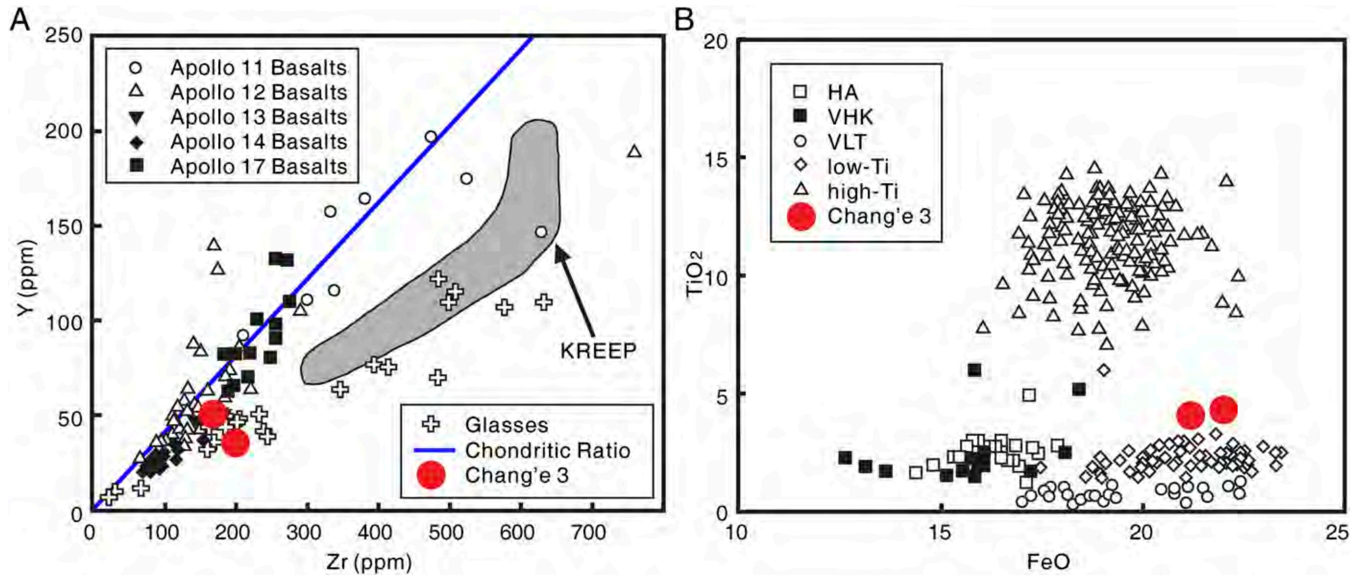

Fig. 3. Compositions of the lunar soil at the landing site. (*A*) Y and Zr plot close to the mixing line with KREEP, different from Apollo basalts (14). (*B*) The FeO and TiO_2 contents plot in the gap between the high-Ti and low-Ti basalt samples (15).

is consistent with the average Apollo mare soils that consist of 16.3 vol % plagioclase and 18.6 vol % pyroxenes (1). The Apollo mare soils also contain abundant impact glass and volcanic glass with minor olivine (~3.4 vol %); however, they cannot be decoded from the reflectance spectra. Furthermore, the FeO and TiO_2 concentrations of the lunar soil can be

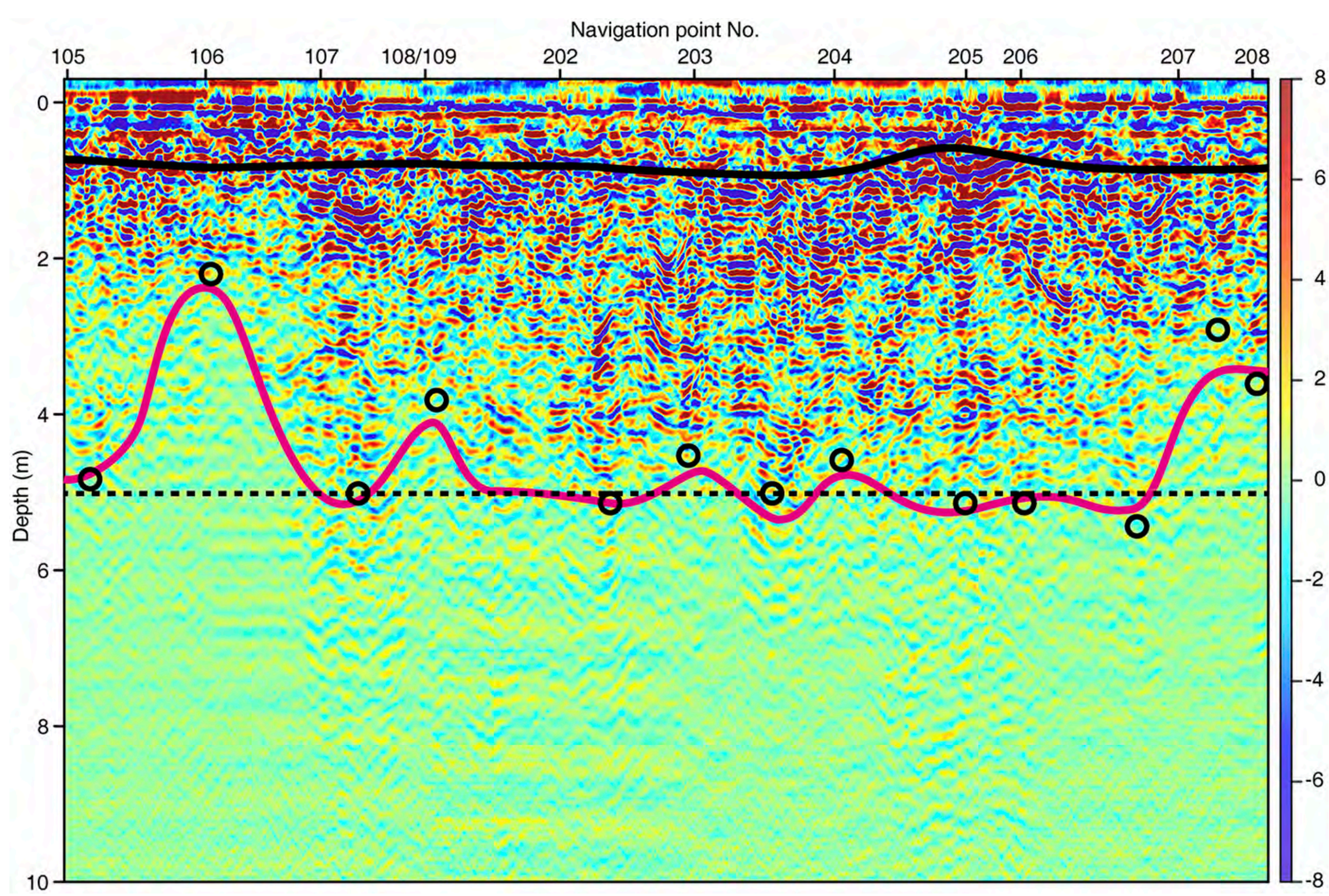

Fig. 4. Migration result of channel 2B of LPR. The profile is about 73 m long. Bold black and pink curves denote the lunar soil sublayer and regolith bottoms picked up manually, respectively. Bold black circles are the depths of lunar regolith picked up from the key traces by time–frequency analyses after migration (shown in *SI Appendix*, Fig. S19). The dashed black line (at 5 m) denotes the best depth estimation of the lunar regolith at the research area.

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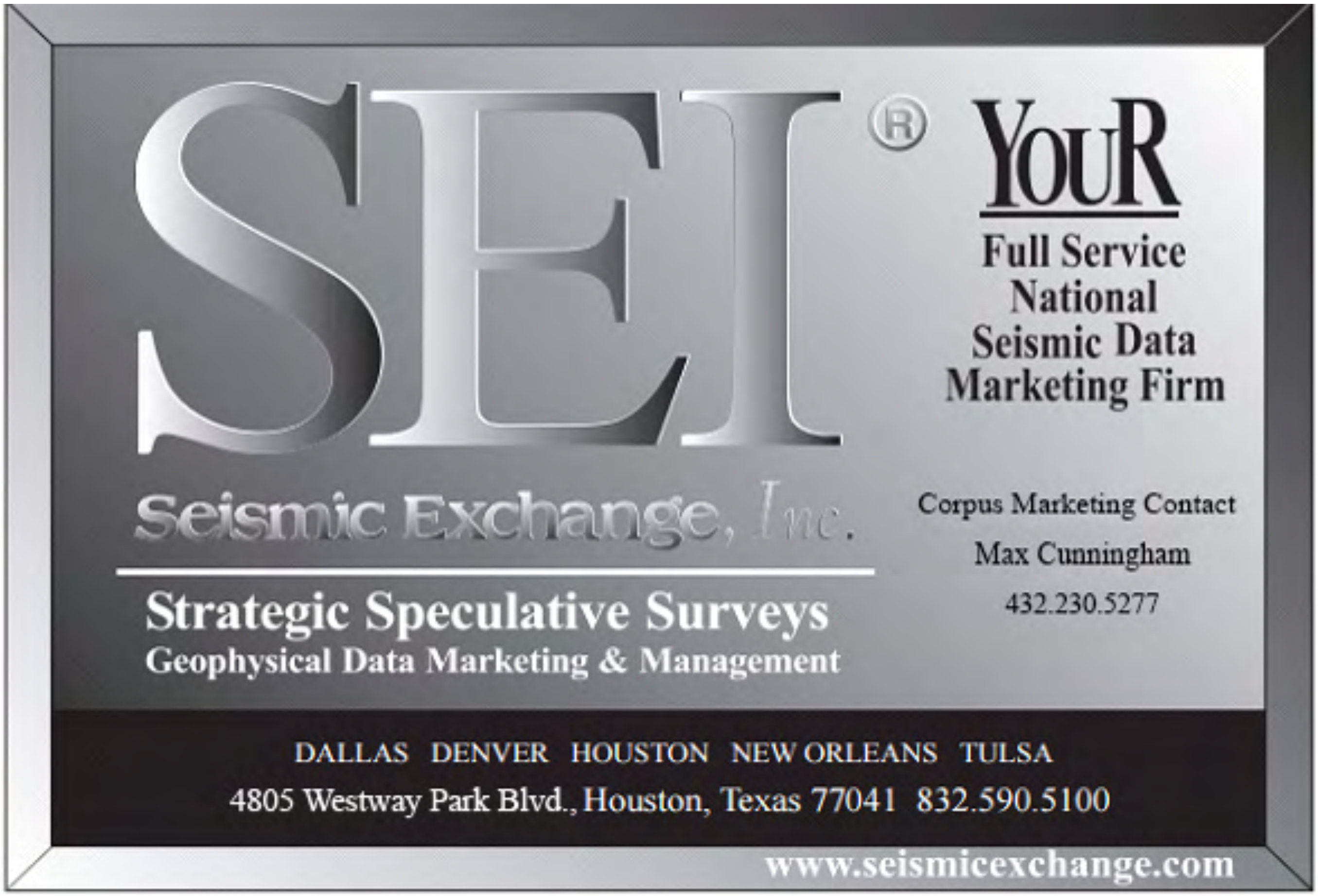
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estimated from the corrections between the compositions and the reflectance spectrum parameters of the Apollo soils (*SI Appendix*, Fig. S9), which are 18.9 wt % (18.7–19.5 wt %) and 6.6 wt % (5.3–9.0 wt %), respectively. The estimated TiO_2 contents are somewhat higher than the APXS analyses, likely due to the shadow of the rough lunar soil surface (*SI Appendix*, Fig. S8). The estimated FeO contents are consistent with the APXS analyses within analytical uncertainties. The space weathering effect (darkening and reddening of the spectra) of the lunar soil can be indicated by the optical maturity index (18), which ranges from 0.098 to 0.158 with an exception of 0.312 for CD005 (*SI Appendix*, Table S2). The higher values of the optical maturity index and the spectral reflectance of CD005 may be due to blowing the top dusts off the lunar surface by the rocket during the descent of Chang'e-3 because CD005 is located closest to the lander (*SI Appendix*, Table S2). The optical maturity index values of CD006–CD008 suggest submature or mature lunar soil, undistinguishable from the Apollo mare soils. This is inconsistent with the rocky surface and the presence of abundant rocks in the lunar soil at the landing site (*SI Appendix*, Fig. S2), which is suggestive of a young age for the Chang'e-3 landing site. However, it has been noticed that there was no clear correlation between the optical maturity index and the ages of the Apollo mare soils (18).

Lunar Regolith Layer Thickness

The lunar regolith layer and the underlying basalt units at the landing site have been detected by the onboard LPR, which has two frequency channels, i.e., channel 1 at 60 MHz and channel 2 at 500 MHz. The echoes were processed using preprocessing, migration and time–frequency analysis methods that are commonly used in seismic exploration (*SI Appendix*). Fig. 4 displays the LPR profile of channel 2 with a total distance of 73 m along the Yutu's track. The relative dielectric constant ε_r increases from 2.1 at the surface to 6.5 at a depth of 10 m, based on the function of lunar soil density with depth (19) and a model of the lunar regolith. We propose that the homogeneous uppermost sublayer contains 5.7 vol % of basaltic blocks determined from the high-resolution images of the landing camera (*SI Appendix*, Fig. S2). Then, we assume that the rock debris content of the lunar regolith increases with depth to 100% at 10 m deep. The high-frequency LPR echoes clearly exhibit an uneven bottom of the lunar regolith, and the depth varies from 2.2 m to 5.4 m with a median value of ~5 m (Fig. 4).

The thickness of the lunar regolith layer can also be constrained by high-resolution morphology of craters taken by the landing camera of Yutu. There are two large craters in the landing region (Fig. 2). The larger one (crater A, 18 m in diameter) is blocky, indicative of penetrating the regolith layer and excavating the underlying bedrock, whereas the other (crater B, 13.7 m in diameter) has few blocks, and hence, it is inside the regolith layer. The depths of both craters were calculated to 3.7 m and 4.9 m using the impacting model of the lunar regolith (www.lpi.usra.edu/lunar/tools/lunarcratercalc/). The depths of 3.7 m and 4.9 m can be referred to as the range of the regolith layer thickness, which is consistent with the LPR measurement. The ground-based LPR measurement of the lunar regolith layer thickness clarifies the wide range in previous estimations from 2.6 m (20) to 7.5 m (21) using the crater morphology method, or 6.2 ± 2.0 m (5) and 6.4 ± 1.7 m (22) based on lunar radar sounder data, in the same young, high-Ti region of Mare Imbrium. A thickness of 8.5–12.2 m of the regolith layer in the Apollo highlands was measured with seismology (4), but the lunar regolith layer thickness of 2–8 m at the Apollo mare sites was estimated (1). In addition, a much thicker regolith (8–32 m, with a median depth of 11 m) was estimated in three Eratosthenian mare areas (2.0–2.5 Ga) (23). Based on the positive correlation between regolith layer thickness and age of the surface (5), the regolith layer thickness at the young Chang'e-3 landing site could be considered to be the minimum of the global surface because of its young age of 3.0 Ga (7) or 2.0–2.3 Ga (12). The thick regolith layer at the Chang'e-3 landing site may be partially attributed to the ejecta deposits from a crater ~450 m in diameter, which locates ~60 m west to the lander. However, the high-resolution descending images reveal no recognizable modification of the distribution pattern of small craters on the surface (Fig. 2). The thickness of ejecta deposits must be less than 20 cm; otherwise, the craters <0.5 m in diameter would have been buried. Hence, the echoes detected by the LPR are mainly from the regolith layer rather than the ejecta deposits of the nearby crater. The mean thicknesses of the lunar regolith layer at Apollo mare sites were generally reported to 2–8 m (1), and the lower range could be somewhat underestimated because these sites are significantly older (3.8–3.1 Ga). This is also confirmed by the blocky nature of the Chang'e landing site, which suggests a thinner regolith layer than the Apollo sites.

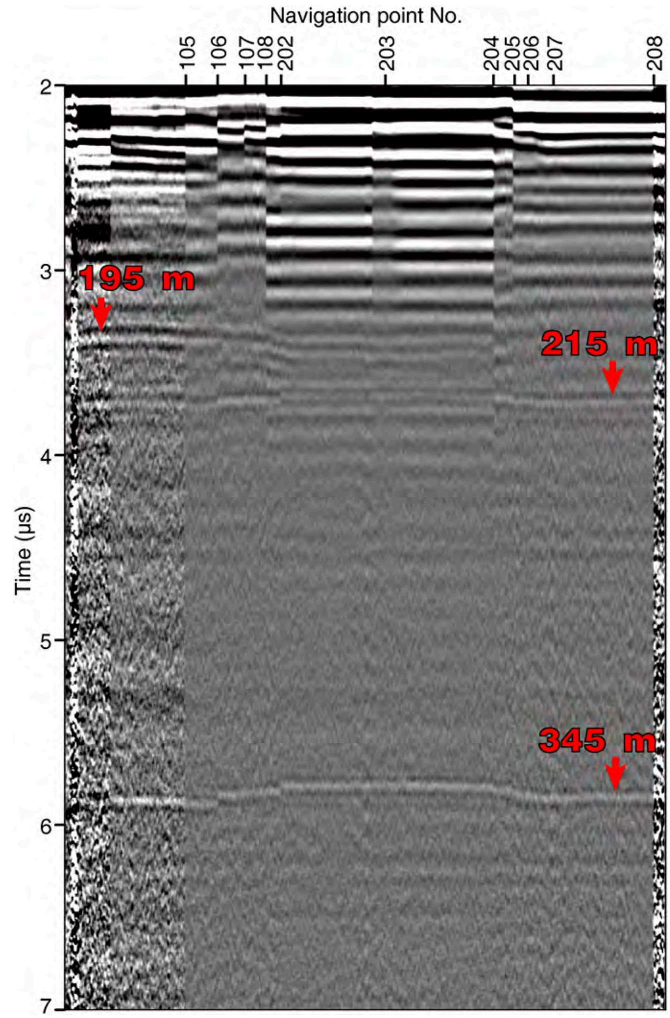

Fig. 5. The LPR profile of channel 1.

In Fig. 4, the uppermost sublayer (~0.7 m in thickness) can be observed. The presence of this sublayer is independent of the model of the lunar regolith we used (*SI Appendix*, Figs. S16 and S17). This homogeneous sublayer likely represents the well–plowed-up top zone of the lunar regolith caused by small impacts. The measured thickness of ~0.7 m of the sublayer is consistent with that of the homogeneous zone (~60 cm) at the top of Apollo 17 deep drill cores (1).

Underlying Basalt Units

The underlying basalt units were probed by the low-frequency LPR echoes. Three obvious reflectors can be observed at depths of 195 m, 215 m, and 345 m (Fig. 5), using $\varepsilon_r = 6.5$ (1). These reflectors likely indicate buried regolith layers formed during flooding hiatus of lava flows in the northeastern Mare Imbrium. This is consistent with the presence of three main types of basalt units in Mare Imbrium, based on variation of FeO and TiO_2 contents (13, 14). These basalt units were dated 3.3–3.5 Ga, 3.0 Ga, and 2–2.5 Ga (7, 12, 24). The lava flows originated from the vent area near the crater Euler (over 700 km south to the landing site) and extended north 1,200 km, 600 km, and 400 km from older low-Ti basalts to the overlying high-Ti flows (*SI Appendix*, Fig. S1). The buried regolith layers between these basalt units are expected, produced by asteroid impacts during the time periods between the eruptions of the basalt units, which are likely responsible for these significant reflection horizons. Hence, the thickness of these three basalt units is 195 m, 20 m, and 130 m, from the top to the bottom, respectively.

Based on the effects of lava flow on lunar crater populations, the thickness of lava flows in the southwest Mare Imbrium were determined to 30–60 m (25) or six flow units with an average of 32–50 m (26). The much thicker uppermost basalt unit determined by Yutu's LPR suggests a sequence of lava flooding events (e.g., refs. 3–6) during a short period, and the individual flows cannot be detected by the LPR because of little regolith produced in the short hiatus. The total thickness of the top two basalt units (both high Ti) can be constrained by morphology of small craters with diameters of 0.4–4.0 km. The distribution of the TiO_2 contents of the rims and proximal ejecta deposits of these craters determined from compositional mapping data (14) revealed whether or not the craters have penetrated the overlying layer and excavated the bedrock beneath. The smallest craters with a diameter of 0.4–1.0 km show a peak at ~5.0 wt % TiO_2 with a low-TiO_2 tail, whereas that of large craters has a low-TiO_2 peak at ~2.5 wt % (*SI Appendix*, Fig. S7). The high-TiO_2 peak is similar to the in situ APXS analyses and the remote sensing results (27, 28). The low-TiO_2 tail of the smallest craters is due to excavating the underlying low-Ti basalt unit, as indicated by the low-TiO_2 peak for the larger craters (1–4 km in diameter) and the presence of old low-Ti basalt about 10 km north to the landing site. This result sets up a range of the total thickness of the upper two basalt units, from significantly larger than 109 m (depth of a crater with 0.4-km diameter) to obviously less than 270 m (depth of a crater with a 1-km diameter). This is consistent with the total thickness (210 m) of the upper two reflectors of LPR. Two subsurface layers in the eastern Mare Imbrium (36.0° N, 15.3° W) have been detected by lunar radar sounder on the Kaguya spacecraft, with depths of 250 m and 454–460 m (29). The footprint of the lunar radar sounder is located on the old low-Ti basalt unit (29), and the first reflector could be assigned to the third echo of Yutu's LPR. However, the depth of 250 m is nearly twice of the thickness of the old low-Ti basalt unit determined by Yutu's LPR. In addition, the deeper layer at 454–460 m measured by Kaguya spacecraft has not been detected by Yutu's LPR.

Conclusions

The chemical compositions of the lunar soil at the Chang'e-3 landing site were determined in situ by APXS, including trace elements of Zr, Sr, Y, and Nb. Its higher FeO (21.3–22.1 wt %) and TiO_2 contents (4.0–4.3 wt %) and lower Al_2O_3 content (10.5–11.5 wt %) compared with the Apollo and Luna soil samples suggest a new type of basalt beneath, which has not yet been sampled in previous missions. The nearly flat KREEP-normalized abundance pattern of K, Zr, Y, and Nb suggests assimilation of the underlying KREEP material. The mineral abundances decoded from the ground-based measurements of the reflectance spectra of the lunar soil are similar to Apollo mare soil.

The thickness of the lunar regolith layer was measured with the LPR to be ~5 m. This is significantly larger than what we expected for a young mare site dated about 2.0–3.0 Ga (7, 12). Such a thick lunar regolith layer is unlikely attributed to ejecta deposits from a nearly crater because no significant modification on the surface was observed in the high-resolution images taken by the descending camera. In addition, an upper sublayer of ~70 cm was detected, which has a feature of lacking rocks. This argues against a detectible layer of the ejecta deposit along the lunar rover's track. Our LPR imaging results show that the thickness of the global lunar regolith layer was underestimated in previous studies (e.g., refs. 1, 20).

The presence of three basalt units detected by the LPR is consistent with the distribution of three main basalt units in the northern Mare Imbrium (*SI Appendix*, Fig. S1). The thickness of 195 m of the top basalt unit indicates no significant cessation of volcanic eruption in the Imbrium basin until 2.0–3.0 Ga, different from a gradual cessation of magma eruption in the Imbrium basin (30). This could be at least partially attributed to high concentrations of radionuclides in the Procellarum KREEP Terrane. The high-Ti basalt was probably formed via partial melting of ilmenite-rich lunar mantle reservoir, followed by ascending to the Imbrium basin with 10–20% contamination of the KREEP material.

Methods

The chemical compositions of the lunar soils were determined from the APXS analyses, calibrated with two analyses of the onboard basaltic working reference and a set of standards that were measured in laboratory. All of the original APXS data are in 2B level and have been corrected for background and peak overlapping (for data processing details, see *SI Appendix*, S2).

The mineral abundances, optical maturity index, and the contents of FeO and TiO_2 of the lunar soil were achieved from the VNIS data in 2B level. The VNIS spectra were combined from those measured separately by the VIS/NIR imaging spectrometer (450–945 nm) and the shortwave IR (SWIR) (900–2395 nm), and they were reduced to repair bad lines and make flat field corrections and converted to reflectance. The Modified Gaussian Model was applied to decode the VNIS spectra, and the Apollo mare soils data were used to calibrate the results (for data handling, see *SI Appendix*, S4).

The lunar regolith layer was detected by the high-frequency channel (500 MHz, channel 2), and the depths of underlying basalt units were detected by the low-frequency channel (60 MHz, channel 1) of LPR on the Yutu rover. The 2B level data of channel 2 were processed using spherical spreading amplitude compensation and filtered by the second-order Butterworth filter. The time–frequency analysis was applied to the channel 2 data. The depths of the lunar soil sublayer and the lunar regolith bottom were estimated using the migration method. For channel 1, the 2B level data were filtered by band-pass Butterworth filter and 2D median filter (for full technical details, see *SI Appendix*, S5).

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Geology of the Big Bend National Park, Texas, by C. A. Berkebile. 26 p., 1984.
CCGS 112G $12.00

GEO LINK POST

http://www.lib.utexas.edu/books/landsapes/index.php Free service. Rare, fragile, hard-to-find, public domain documents covering various topics about the landscape of Texas. Includes the Texas Geological Survey from 1887 until 1894.

USGS TAPESTRY OF TIME AND TERRAIN http://tapestry.usgs.gov The CCGS is donating to all of the 5th and 6th grade schools in the Coastal Bend. Check it out--it is a spectacular map. You might want to frame one for your own office. The one in my office has glass and a metal frame, and It cost $400 and it does not look as good as the ones we are giving to the schools.

FREE TEXAS TOPOS'S http://www.tnris.state.tx.us/digital.htm these are TIFF files from your state government that can be downloaded and printed. You can ad them to SMT by converting them first in Globalmapper. Other digital data as well.

FREE NATIONAL TOPO'S http://store.usgs.gov/b2c_usgs/b2c/start/(xcm=r3standardpitrex_prd)/.do go to this webpage and look on the extreme right side to the box titled TOPO MAPS DOWNLOAD TOPO MAPS FREE.

http://www.geographynetwork.com/ Go here and try their top 5 map services. My favorite is 'USGS Elevation Date.' Zoom in on your favorite places and see great shaded relief images. One of my favorites is the Great Sand Dunes National Park in south central Colorado. Nice Dunes.

http://antwrp.gsfc.nasa.gov/apod/asropix.html Astronomy picture of the day--awesome. I click this page everyday.

http://www.spacimaging.com/gallery/ioweek/iow.htm Amazing satellite images. Check out the gallery.

http://www.ngdc.noaa.gov/seg/topo/globegal.shtml More great maps to share with kids and students.

www.ccgeo.org Don't forget we have our own we page.

http://terra.nasa.gov/gallery/ Great satellite images of Earth.

www.ermaper.com They have a great free downloadable viewer for TIFF and other graphic files called ER Viewer.

http://terrasrver.com Go here to download free aerial photo images that can be plotted under your digital land and well data. Images down to 1 meter resolution, searchable by Lat Long coordinate. Useful for resolving well location questions.

TYPE LOGS OF SOUTH TEXAS FIELDS by Corpus Christi Geological Society

NEW (2019)TYPE LOGS IN RED; lost now found

ARANSAS COUNTY
Aransas Pass/McCampbell Deep
Bartell Pass
Blackjack
Burgentine Lake
Copano Bay, South
Estes Cove
Fulton Beach
Goose Island
Half Moon Reef
Nine Mile Point
Rockport, West
St. Charles
Tally Island
Tract 831-G.O.M. (offshore)
Virginia

BEE COUNTY
Caesar
Mosca
Nomanna
Orangedale(2)
Ray-Wilcox
San Domingo
Tulsita Wilcox
Strauch_Wilcox

BROOKS COUNTY
Ann Mag
Boedecker
Cage Ranch
Encintas
ERF
Gyp Hill
Gyp Hill West
Loma Blanca
Mariposa
Mills Bennett
Pita
Tio Ayola
Tres Encinos

CALHOUN COUNTY
Appling
Coloma Creek, North
Heyser
Lavaca Bay
Long Mott
Magnolia Beach
Mosquito Point
Olivia
Panther Reef
Powderhorn
Seadrift, N.W.
Steamboat Pass
Webb Point
S.E. Zoller

CAMERON COUNTY
Holly Beach
Luttes
San Martin (2)
Three Islands, East
Vista Del Mar

COLORADO COUNTY
E. Ramsey
Graceland N. Fault Blk
Graceland S. Fault Blk

DEWITT COUNTY
Anna Barre
Cook
Nordheim
Smith Creek
Warmsley
Yorktown, South

DUVAL COUNTY
DCR-49
Four Seasons
Good Friday
Hagist Ranch
Herbst
Loma Novia
Petrox
Seven Sisters
Seventy Six, South
Starr Bright, West

GOLIAD COUNTY
Berclair
North Blanconia
Bombs
Boyce
Cabeza Creek, South
Goliad, West
St Armo
Terrell Point

HIDALGO COUNTY
Alamo/Donna
Donna
Edinburg, West
Flores-Jeffress
Foy
Hidalgo
LA Blanca
McAllen& Pharr
McAllen Ranch
Mercedes
Monte Christo, North
Penitas
San Fordyce
San Carlos
San Salvador
S. Santallana
Shary
Tabasco
Weslaco, North
Weslaco, South

JACKSON COUNTY
Carancahua Creek
Francitas
Ganado & Ganado Deep
LaWard, North
Little Kentucky
Maurbro
StewartSwan Lake
Swan Lake, East
Texana, North
West Ranch

JIM HOGG COUNTY
Chaparosa
Thompsonville,N.E.

JIM WELLS COUNTY
Freebom
Hoelsher
Palito Blanco
Wade City

KARNES COUNTY
Burnell
Coy City
Person
Runge

KENEDY COUNTY
Candelaria
Julian
Julian, North
Laguna Madre
Rita
Stillman

KLEBERG COUNTY
Alazan
Alazan, North
Big Caesar
Borregos
Chevron (offshore)
Laguna Larga
Seeligson
Sprint (offshore)

LA SALLE COUNTY
Pearsall
HAWKVILLE:EAGLEFORD

LAVACA COUNTY
Halletsville
Hope
Southwest Speaks
Southwest Speaks Deep

LIVE OAK COUNTY
Atkinson
Braslau
Chapa
Clayton
Dunn
Harris
Houdman
Kittie West-Salt Creek
Lucille
Sierra Vista
Tom Lyne
White Creek
White Creek, East

MATAGORDA COUNTY
Collegeport

MCMULLEN COUNTY
Arnold-Weldon
Brazil
Devil's Waterhole
Hostetter
Hostetter, North

NUECES COUNTY
Agua Dulce (3)
Arnold-David
Arnold-David, North
Baldwin Deep
Calallen
Chapman Ranch
Corpus Christi, N.W.
Corpus Christi West C.C.
Encinal Channel
Flour Bluff/Flour Bluff, East
GOM St 9045(offshore)
Indian Point
Mustang Island
Mustang Island, West
Mustang Island St.
889S(offshore)
Nueces Bay/Nueces Bay
West
Perro Rojo
Pita Island
Ramada
Redfish Bay
Riverside
Riverside, South
Saxet
Shield
Stedman Island
Turkey Creek

REFUGIO COUNTY
Bonnieview/Packery Flats
Greta
La Rosa
Lake Pasture
Refugio, New
Tom O'Connor

SAN PATRICIO COUNTY
Angelita East
Commonwealth
Encino
Enos Cooper
Geronimo
Harvey
Hiberia
Hodges
Mathis, East
McCampbell Deep/Aransas Pass
Midway
Midway, North
Odem
Plymouth
Portilla (2)
Taft
Taft, East
White Point, East

STARR COUNTY
El Tanque
Garcia
Hinde
La Reforma, S.W.
Lyda
Ricaby
Rincon
Rincon, North
Ross
San Roman
Sun
Yturria

VICTORIA COUNTY
Helen Gohike, S.W.
Keeran, North
Marcado Creek
McFaddin
Meyersville
Placedo

WEBB COUNTY
Aquilares/Glen Martin
Big Cowboy
Bruni, S.E.
Cabezon
Carr Lobo
Davis
Hirsch
Juanita
Las Tiendas
Nicholson
O'Hem
Olmitos
Tom Walsh

WHARTON COUNTY
Black Owl

WILLACY COUNTY
Chile Vieja
La Sal Vieja
Paso Real
Tenerias
Willamar

ZAPATA COUNTY
Benavides
Davis, South
Jennings/Jennings, West
Lopeno
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Pok-A-Dot

ZAVALA COUNTY
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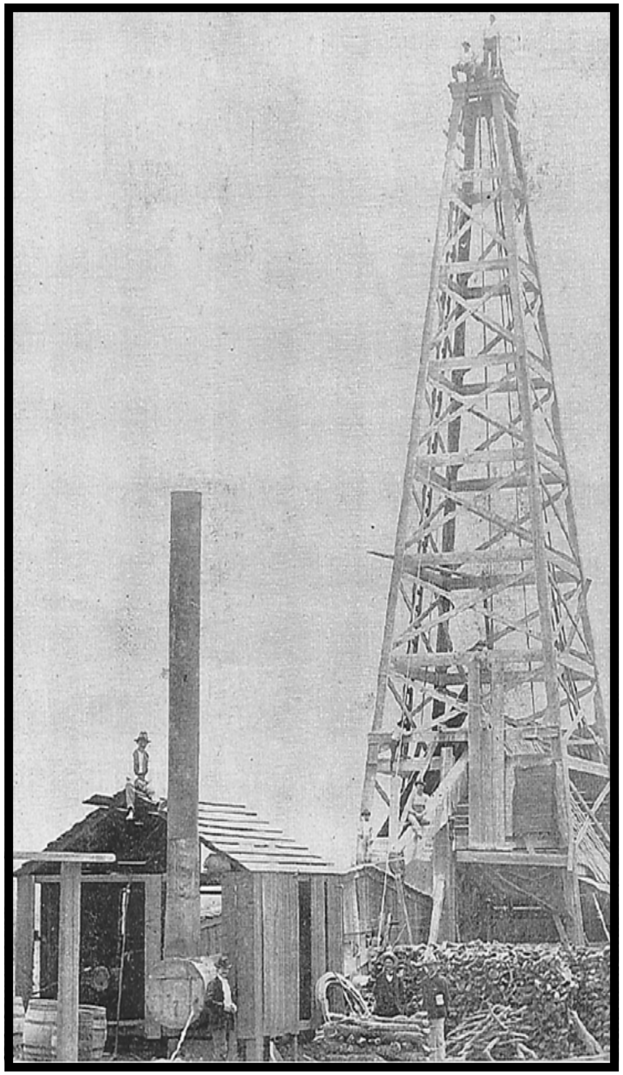

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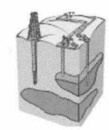

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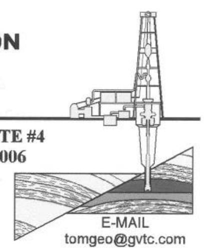

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