AMES GRANT
IN-46-CR
114233
P.12

Final Technical Report

for

Grant NSG-2284

STUDIES IN AEOLIAN GEOLOGY

for the period December 1, 1977 to February 28, 1986

Submitted to

Ames Research Center
National Aeronautics and Space Administration
Moffett Field, California 94035
ATTN: B. Hastings

and

NASA Scientific and Technical Information Facility
P.O. Box 8757
Baltimore Washington International Airport
Maryland 21240

Principal Investigator ______________________ 1/14/88
(date)

Ronald Greeley
Department of Geology
Arizona State University
Tempe, AZ 85287-1404

(NASA-CR-182328) STUDIES IN AEOLIAN GEOLOGY Final Technical Report, 1 Dec. 1977 - 28 Feb. 1986 (Arizona State Univ.) 12 p Avail: NTIS HC A03/MF A01 CSCL 08G

N88-13828

Unclas

G3/46 0114233

1.0 OBJECTIVE

The objective of this research was to assess the significance of aeolian (windblown) processes in the evolution of planetary surfaces. The approach was to use wind tunnel simulations, field studies of possible analogs, and analyses of spacecraft data.

2.0 BACKGROUND

Many physical and chemical processes modify planetary surfaces. On planets having an atmosphere, wind plays an important role in shaping the surface through the redistribution of fine grained material. In addition, bedrock may be eroded to produce particles and the particles transported for deposition in other areas. This process is readily observable on Earth today and is evident in the geological record.

Even in the tenuous atmosphere of Mars, it is clearly demonstrated that aeolian processes are important on that planet. Mariner 9 and Viking results show abundant wind-related landforms, including dune fields and yardangs. Viking lander images show drifts of windblown particles. On Venus, measurements made by Soviet Venera spacecraft and extrapolations from the Pioneer Venus probe show that surface winds are capable of transporting materials and suggest that aeolian processes may operate on that planet as well. In addition, one of the satellites of Saturn, Titan, has an atmosphere of about 1.6 bar pressure on the surface, as well as a possible frozen surface of ice, suggesting the possibility of aeolian activity.

In order to understand the present surface dynamics and the geological evolution of surfaces for planets and satellites subjected to wind, it is important to know the nature of aeolian processes. Factors such as threshold speeds (minimum wind velocity needed to move particles), rates of erosion, trajectories of windblown particles, and flow fields over various landforms are important aspects of the problem.

3.0 APPROACH

The approach employed in this investigation combined the results from wind tunnel experiments and field analog studies for interpretation of spacecraft data. The principal wind tunnels involved in the study were:

1) Planetary Wind Tunnel at Arizona State University; this is a 40-foot open-circuit, atmospheric boundary-layer system used for investigations of the wind flow-field around modelled landforms such as craters and yardangs.

2) Martian Surface Wind Tunnel at NASA-Ames; this 45-foot open-circuit tunnel operates at a range of atmosphere pressures (from 1 bar to 3 mb) and is used to study the physics of windblown particles under martian atmospheric conditions.

3) The Venusian Wind Tunnel at NASA-Ames is a closed-circuit wind tunnel used to simulate the movement of windblown particles on Venus and to analyze the resulting bedforms such as ripples.

The field analog studies involved the analysis of active sand sheets in geological terrains that are considered to be analogous to those on Mars and Venus. Spacecraft data analysis involved the Mariner 9 and Viking data sets for Mars and the Venera data sets for Venus. This activity is primarily image interpretation of aeolian features, from both orbital views (e.g., dune fields, yardangs, variable features) and from landers, such as Viking and Venera.

4.0 RESULTS

Results from this study and related investigations are given in the publications, abstracts, and presentations indicated in section 5.0. In addition, a selection of publication reprints is given as an appendix herewith.

General Reviews

In 1986, a review "Aeolian Activity as a Planetary Process" (Greeley, 1986) was published as a chapter in the book the *Physics of Desertification*. Also in 1986, a review chapter "Aeolian Landforms: Laboratory and Field Studies" (Greeley, 1986) was published in the book *Aeolian*

Geomorphology. These publications demonstrated the comparative planetology aspects of the investigation and showed the terrestrial community the relevance that the study of other planets has for understanding a basic process--wind--on Earth.

Field Studies

Field studies were an integral part of this investigation because they provide an important "check" on theoretical modelling and laboratory simulations. Field work was conducted at the Amboy lava field, California, Rogers Lake, California, and the Gran Desierto-Pinacate region of Sonora, Mexico. At Amboy, insight was gained into the formation of desert pavement surfaces, the flow around a large topographic obstruction, and the influence of lava surface roughness on the atmospheric boundary layer and the potential for aeolian activity (Greeley and Iversen, 1986).

At Rogers Lake, a preliminary study of yardang formation and evolution was completed for comparison with wind tunnel simulations (Ward and Greeley, 1984). Several attempts were made to instrument the yardangs to obtain high quality wind data, but all attempts failed due to unfavorable winds (wrong direction, insufficient strength, equipment failures).

A study of the Shuttle Imaging Radar data for volcanic and aeolian features in the Gran Desierto-Pinacate region (Greeley et al., 1985) was completed which showed that some windblown deposits can be detected via orbital radar. This study led to a more general assessment of remote sensing of the dune fields and the classification of dune types. Preliminary results were published in 1987 (Lancaster et al., 1987). Final study of a "type" star dune has been submitted for publication.

Venus

Experiments were completed using the Venus Wind Tunnel to detect: a) particle threshold conditions, b) particle velocities, and c) the development of bedforms such as microdunes and ripples (Greeley et al., 1984). Results show that even in the sluggish near-surface winds on Venus, sufficient speed is reached to move particles of sand and gravel size on Venus, although the saltation trajectories are very short. It was also found that substantial material is moved by rolling, a mode of tranportation not normally significiant on Earth, in air. Once entrained--particles in saltation reached nearly the same speed as the wind. Ripples formed in the venusian environment were found to be very small--only a few cm in wavelength; however, structures called microdunes also developed. These features have 10-15 cm wavelengths and mimic, in morphology and mode of advance, full size sand dunes on Earth. These results are markedly different from aeolian activity on either Earth or Mars and are attributed to the high atmospheric density on Venus (Iversen et al., 1987).

Experiments were also run in the Venus Simulator to assess the mechanical erosion of windblown particles and bedrock. As reported in Greeley et al. (1987), it was found that small amounts of the grains were abraded due to impact erosion and transferred to the target rock. Thus, a type of veneer may be expected to form on venusian rocks, the composition of which would be indicative of the windblown material and not necessarily be representative of the "bedrock".

Mars

In the absence of running water, aeolian processes are the dominant medium for altering the surface of Mars today. This part of the investigation included: a) determination of particle threshold for a range of particle size and densities under different martian atmospheric densities, b) assessment of rates of abrasion by windblown particles, and c) analyses of Viking data for dunes and other aeolian features on Mars. Data on threshold obtained using the Martian Surface Wind Tunnel at NASA-Ames were published by Greeley et al. (1980). Results on wind abrasion are given by McKee et al. (1979), Krinsley et al. (1979), and Greeley et al. (1982, 1984, 1985).

Sand dunes of the north pole sand sea of Mars were analyzed by Tsoar et al. (1975), while aeolian deposits in the Syrtis Major region were assessed using a combination of high resolution visual, thermal, and radar data by Zimbelman and Greeley (1981).

Microgravity Experiments

Gravity is an important term in the expressions describing the movement of windblown particles. The space station may afford the unique opportunity to conduct experiments in the near-absence of gravity to assess its role in aeolian processes. A wind tunnel apparatus was designed and flown on board the NASA microgravity aircraft as a prototype for a system which might eventually be flown in space. As reported by White et al. (1987), the results from these feasibility experiments are in good agreement with theory and demonstrate that the apparatus could be used on the space station and contribute to the general understanding of aeolian processes.

5.0 Bibliography of work wholly or partly supported through this investigation.

Journal Papers

1977, A study of variable features on Mars during the Viking nominal mission, *J. Geophys, Res.*, *82,* 4167-4188, Veverka, J., I. Thomas, and R. Greeley.

1978, Crater streaks in the Chryse Planitia region, Mars, *Icarus, 34,* 556-567, Greeley, R., R. Papson, and J. Veverka.

1978. Field guide to Amboy lava flow, San Bernadino Co., CA., *in* Greeley, R. et al., eds., *Aeolian features of southern California: A comparative planetary geology guidebook,* 23-52, Greeley, R. and J.D. Iversen.

1978, Abstracts for the Planetary Geology Field Conference on Aeolian Processes, *NASA TM-78455,* 59 p., Greeley, R. and D. Black.

1978, Atmospheric and wind tunnel experiments of the Amboy Crater sand-covered lava flow, Engineering Res. Inst., Iowa State Univ., Ames, Iowa, Interim Report, 79 p. *ISY-ERI-78235,* Greeley, R., J. Iversen.

1978, *Aeolian Features of Southern California: A Comparative Planetary Geology Guidebook,* NASA, 264 p., Greeley, R., M. Womer, R. Papson, and P. Spudis, eds.

1979, Silt-clay aggregates on Mars, *J. Geophys. Res., 84,* 6248-6254, Greeley, R.

1979, Abrasion of windblown particles on Mars: Erosion of basaltic sand under simulated martian conditions, *Icarus, 39,* 364-384, Krinsley, D.K., R. Greeley, and J. Pollack.

1979, Mars: The north polar sand sea and related wind patterns, *J. Geophys. Res., 84,* 8167–8182, Tsoar, H., R. Greeley, and A.R. Peterfreund.

1980, Threshold wind speeds for sand on Mars: Wind tunnel simulations, *Geophys. Res. Lett.,* 7(2), 121-124, Greeley, R., R. Leach, B. White, J. Iversen, and J. Pollack.

1980, Dust storms on Mars: Considerations and simulations, *Geol. Soc. Amer. Spec. Paper, 186,* 101-121, Greeley, R., B.R. White, J.B. Pollack, J.D. Iversen, and R.N. Leach.

1981, Aeolian activity as a planetary process, *Mem. Soc. Ast., Italy,* 409-418, Greeley, R.

1981, High resolution visual, thermal, and radar observations in the northern Syrtis Major region of Mars, *Proc. Lunar Planet. Sci., 12B,* 1419-1429, Zimbelman, J.R. and R. Greeley.

1982, Aeolian modification of planetary surfaces, *in* Coradini, A. and M. Fulchignoni, eds., *The Comparative Study of the Planets,* NATO Advanced Study Institute Series, D. Reidel Publ., Dordrecht, 419-434, Greeley, R.

1982, Rate of wind abrasion on Mars, *J. Geophys. Res., 87,* 10009-10029, Greeley, R., R. Leach, S.H. Williams, B.R. White, J. Pollack, D.H. Krinsley,and J.R. Marshall.

1982, Surface properties of ancient terrain in the northern hemisphere of Mars, *J. Geophys. Res.*, *87,* 10181-10189, Zimbelman, J.R. and R. Greeley.

1983, Velocities of windblown particles in saltation: Preliminary laboratory and field measurements, *in Eolian Sediments and Processes,* Elsevier, Amsterdam, 133-148, Greeley, R., S.H. Williams, and J.R. Marshall.

1984, Microdunes and other aeolian bedforms on Venus: Wind tunnel simulations, *Icarus, 60,* 152-160, Greeley, R., J.R. Marshall, and R.N. Leach.

1984, Windblown sand on Venus: Preliminary results of laboratory simulations, *Icarus, 57,* 112–124, Greeley, R., J. Iversen, R. Leach, J. Marshall, B. White, and S. Williams.

1984, Abrasion by aeolian particles: Earth and Mars, *NASA CR 3788,* 50 p., Greeley, R., S. Williams, B. R. White, J. Pollack, J. Marshall, and D. Krinsley.

1984, Martian crater dark streaks - explanation from wind tunnel experiments, *Icarus, 58,* 358–362, Iversen, J.D. and R. Greeley.

1984, Evolution of yardangs at Rogers Lake, California, *Geol. Soc. Amer. Bull., 95,* 829-837, Ward, W.A. and R. Greeley.

1985, Transport of venusian rolling "stones" by wind?, *Nature, 313,* 771-773, Greeley, R. and J.R. Marshall.

1985, Analyis of the Gran Desierto-Pinacate Region, Sonora, Mexico, via shuttle imaging radar, *NASA CR-177356,* 44 p., Greeley, R., P.R. Christensen, J.F. McHone, Y. Asmerom, and J.R. Zimbelman.

1985, Wind abrasion on Earth and Mars, *in Models in Geomorphology,* Woldenberg, M.J., ed., Allen and Unwin Publ., London, 373-422, Greeley, R., S.H. Williams, B.R. White, J.B. Pollack, and J.R. Marshall.

1985, "Microdunes" and other aeolian bedforms in high-density atmospheres, *Proc. Physics of Windblown Sand Symposium,* Aarhus, Denmark, 369-376, Bougan, S. and R. Greeley.

1986, Aeolian activity as a planetary process, *in Physics of Desertification*, El-Baz, F. and M.H.A. Hassan, eds., Martinus Nijhoff Publ., Dordrecht, 159-190, Greeley, R.

1986, Aeolian landforms: Laboratory simulations and field studies, *in Aeolian Geomorphology,* Nickling, W., ed., Allen & Unwin, Inc., Boston, 195-211, Greeley, R.

1986, Aeolian processes and features at Amboy Lava Field, California, *in Physics of Desertification*, El-Baz, F. and M.H.A. Hassan, eds., Martinus Nijhoff Publ., Dordrecht, 290-317, Greeley, R. and J.D. Iversen.

1986, Individual particles and the martian aeolian action--A review, *Sedimentary Geol., 47*, 167–189, Krinsely, D. and R. Greeley.

1987, Physical and chemical modification of the surface of Venus by windblown particles, *Nature, 327,* 313-315, Greeley, R., J.R. Marshall, and J.B. Pollack.

1987, Dunes of the Gran Desierto Sand Sea, Sonora, Mexico, *Earth Surface Processes and Landforms, 12,* 277-288, Lancaster, N., R. Greeley, and P.R. Christensen.

1987, Saltation threshold experiments conducted under reduced gravity conditions, *Amer. Inst. Aeronautics and Astronautics,* AIAA-87-0621, 9 p., White, B.R., R.N. Leach, R. Greeley, and J.D. Iversen.

1987, Aeolian threshold: Effect of density ratio, *Sedimentology, 34,* 699-706, Iversen, J.D., R. Greeley, J.R. Marshall, and J.B. Pollack.

Abstracts

1978, Geology and aeolian features of the Hellas Basin floor, *in* Abstracts for the Planetary Geology Field Conference on Aeolian Processes, *NASA TM-78455,* 19-21, Greeley, R., P.D. Spudis, and D. Johannesen.

1978, Comparison of wind-tunnel-model and atmospheric full-scale experiments of the Amboy crater and adjacent topography, *in* Abstracts for the Planetary Geology Field Conference on Aeolian Processes, *NASA TM-78455,* 24-26, Iversen, J.D. and R. Greeley.

1978, Wind tunnel and field experiments of Amboy Crater - a terrestrial analog to martian crater–associated dark streaks, *in* Reports of Planetary Geology Program, 1978-1979, *NASA TM-79729,* 222-224, Iversen, J.D. and R. Greeley.

1978, Surface textures of sand-sized particles abraded under Earth and martian conditions, *in* Abstracts for the Planetary Geology Field Conference on Aeolian Processes, *NASA TM–78455,* 30-32, Krinsley, D.H. and R. Greeley.

1978, Surface textures of sand-sized particles abraded under Earth and martian conditions, *in* Reports of Planetary Geology Program, 1977-1978, *NASA TM-79729,* 225-227, Krinsley, D.H. and R. Greeley.

1978, Eolian activity in the Tharsis/Syria Planum region on Mars: A summary of Viking and Mariner 9 results, *in* Reports of Planetary Geology Program, 1978-1979, *NASA TM-79729,* 246, Veverka, J., P. Thomas, S. Lee, and R. Greeley.

1978, Wind transport rates on Mars, *in* Reports of Planetary Geology Program 1978-1979, *NASA TM-79729,* 241-243, White, B. and R. Greeley.

1978, Wind transport rates on Mars, *in* Abstracts for Planetary Geology Field Conference on Aeolian Processes, *NASA TM-78455,* 48-51, White, B. and R. Greeley.

1978, Wake of a three-dimensional disturbance in a turbulent boundary layer, *in* Abstracts for Planetary Geology Field Conference on Aeolian Processes, *NASA TM-78455,* 52-56, White, B., J. Iversen, and R. Leach.

1979, A model for the formation of windblown sand-size particles and related structures on Mars, *in* Intern. Coll. on Mars II, *NASA Conf. Pub. 2072,* 32, Greeley, R.

1979, "Steam" injection of dust on Mars: Laboratory simulation, *in* Reports of Planetary Geology Program, 1978-1979, *NASA TM-80339,* 304-307, Greeley, R. and R. Leach.

1979, Mars: Preliminary estimates of rates of wind erosion based on laboratory simulations, *in Lunar and Planet. Conf. X,* 461-463, Greeley, R. and S. Williams.

1979, Simulated aeolian abrasion of quartz and basalt under martian conditions, *in* Intern. Coll. on Mars II, *NASA Conf. Pub. 2072,* 49, Krinsley, D., R. Greeley, and T. McKee.

1979, Sand dunes of the north polar region of Mars: Mapping and analysis, *in Lunar Planet. Sci. X,* 1242-1244, Tsoar, H., R. Greeley, R. Papson, and S. Squyres.

1979, Experimental modeling of erosional windforms, *in* Reports of Planetary Geology Program, *NASA TM-80339,* 326-327, Ward, A.W. and R. Greeley.

1979, Calibration of the MARSWIT tunnel for determination of particle threshold speeds, *in* Reports of Planetary Geology Program, *NASA TM-80339,* 319-321, White, B.R., R. Leach, J.D. Iversen, and R. Greeley.

1979, Infrared characterization of wind streaks on Mars, in *Bull. Amer. Astron. Soc., 11*(3), 576, Peterfreund, A.R. and R. Greeley.

1980, Venus: Consideration of aeolian (windblown) processes, *in Lunar Planet. Sci. XI,* 360–361, Greeley, R., J. Iversen, R. Leach, and J. Pollack.

1980, Dunes related to obstacles on Earth and Mars: Observation and simulation, *in* Reports of Planetary Geology Program, *NASA TM-81776,* 257-259, Tsoar, H. and R. Greeley.

1980, Estimate of characteristic grain sizes for martian dunes, *in Lunar Planet. Sci. XI,* 1169–1171, Tsoar, H. and R. Greeley.

1981, Aeolian processes on Venus, *Inter. Conf. Venus Environ.,* 10, Greeley, R., S. Williams, R. Leach, B. White, J. Iversen, and J. Pollack.

1981, An experimental study of the behavior of electrostatically-charged fine particles in atmospheric suspension, *NASA TM-84211,* 208-210, Marshall, J.R., D. Krinsley, and R. Greeley.

1981, Sand on Mars, *Third Inter. Colloq. on Mars,* 188-190, Peterfreund, A.R., R. Greeley, and D. Krinsley.

1981, Surface roughness effects on aeolian processes: Wind tunnel experiments, *NASA TM-84211,* 195-196, Reding, L.M., S. Williams, R. Leach, B.R. White, and R. Greeley.

1981, Soil transport by winds on Venus, *NASA TM-84211,* 201-202, White, B.R. and R. Greeley.

1981, Formation and evolution of playa ventifacts, Amboy, California, *NASA TM-84211,* 197–199, Williams, S. and R. Greeley.

1982, Wind as a geological process: Earth, Mars, Venus and Titan, *11th Intl. Congress on Sedimentologists,* 63, Greeley, R.

1982, Velocities of windblown particles in saltation: Earth and Mars, *11th Intl. Congress on Sedimentologists,* 63, Greeley, R.

1982, Particle motion of venusian saltation, *NASA TM-85127,* 173-174, White, B.R. and R. Greeley.

1982, Wind abrasion of rocks: Computer simulation, *NASA TM-85127,* 175-176, Greeley, R.

1982, Windblown sand on Venus: Preliminary laboratory simulations, *EOS, 63*(45), 1021, Greeley, R., S. Williams, J.D. Iversen, R. Leach, B.R. White, and J. Pollack.

1982, Simulating aeolian processes on Venus with a high-pressure N2 atmosphere, *NASA TM-85127,* 165-166, Marshall, J., R. Leach, C. Treat, and R. Greeley.

1982, Windblown sand on Venus: Preliminary laboratory simulations, *NASA TM-85127,* 167-169, Greeley, R. and S. Williams.

1983, Radar-visible wind streaks in the Altiplano of Bolivia, *Trans. Amer. Geophys. Union, 64,* 745, Greeley, R., P. Christensen, and R. Carrasco.

1983, SIR-A (radar) analogs to potential Venus surface features, *Abstracts, Geol. Soc. Amer., 15,* no. 6, 585, Greeley, R., P. Christensen, Y. Asmerom, J. McHone, and S. Barnett.

1984, Flux and bedforms of windblown material on Venus, *Lunar Planet. Sci., XV,* 80-81, Bougan, S., R. Greeley, and J. Marshall.

1984, Planetary science experiments aboard Space Station: Workshop report (abs.), *Bull. Amer. Astron. Soc., 16,* 651, Greeley, R.

1984, Wind abrasion on Venus: A means for experimental investigations, in *Repts. Planetary Geology Program, NASA TM-86246,* 67-68, Greeley, R. and J. Marshall.

1984, A space station wind tunnel for studying sediment transport, *XVI Intern. Cong. Theor. Appl. Mech.,* Lyngby, Denmark, Aug. 19-25, 1984, abstr. #184, Iversen, J.D. and R. Greeley.

1984, Venus: Simulations of aeolian bedforms and comparisons with terrestrial aeolian and subaqueous forms, *Trans. Amer. Geophys. Union, 65,* 982, Marshall, J.R., S. Bougan, and R. Greeley.

1984, Desert pavement study at Amboy, California, in *Repts. Planetary Geology Program, NASA TM-86246,* 169-170, Williams, S. and R. Greeley.

1985, Dust storms on Mars: Mechanisms for dust-raising, Workshop on Dust on Mars (S. Lee, ed.), *LPI Tech. Rept. 85-02,* 3-5, Greeley, R.

1985, Microdunes and other aeolian bedforms on Venus: Wind tunnel simulations, *Repts. Planetary Geology Program, NASA TM-87563,* 309, Greeley, R., J.R. Marshall, and R.N. Leach.

1985, Effect of density ratio: Threshold speeds on Venus, *Lunar Planet. Sci. XVI,* 388-389, Iversen, J.D., R. Greeley, J.R. Marshall, R.N. Leach, and B.R. White.

1985, Theoretical investigation of the evolution of eolian landforms, *Repts. Planetary Geology Program, NASA TM-87563,* 580-582, MacKinnon, D.J., A.W. Ward, and R. Greeley.

1985, Aeolian geomorphology from the global prospective, *in* Hayden,R.S., ed., *Global Mega-Geomorphology,* NASA Conf. Publ. 2312, 64-67, Greeley, R.

1985, A comparison of terrestrial saltation flux in the laboratory and the field, *Repts. Planetary Geology Program, NASA TM-87563,* 305-306, Williams, S. and R. Greeley.

1986, Identification of active sand surfaces: Earth and Mars, *Geol. Soc. Amer., Abstracts with Programs, 18,* 544, Blount, H.G., R. Greeley, and P.R. Christensen.

1986, Martian dust: The case for "parna", *in* Workshop on Dust on Mars II, S. Lee, ed., *LPI Tech. Rept.,* No. 86-09, 26-28, Greeley, R.

1986, Toward an understanding of the martian dust cycle, *in* Workshop on Dust on Mars II, S. Lee, ed., *LPI Tech. Rept.,* No. 86-09, 29-31, Greeley, R.

1986, Aeolian-induced surface accretions on venusian rocks: Preliminary laboratory simulations, *EOS, Trans. Amer. Geophys. Union, 67,* 1078, Marshall, J.R., R. Greeley, D.W. Tucker, and J.B. Pollack.

1986, Wind erosion on Mars: Impairment by poor saltation cloud development, *Lunar Planet. Sci. XVII,* 952-953, Williams, S.H. and R. Greeley.

1987, Aeolian mixing and the identification of active sand surfaces on the Earth and Mars, *Lunar Planet. Sci. XVIII,* 95-96, Blount, G., R. Greeley, N. Lancaster, P.R. Christensen, and R. Arvidson.

1987, Bright sand/dark dust: The identification of active sand surfaces on the Earth and Mars, *Repts. Planetary Geology Geophysics Program, NASA TM-89810,* 257-258, Blount, H.G. II, R. Greeley, P.R. Christensen, and R. Arvidson.

1987, Venus: Compositional and mechanical effects from windblown grains, *Lunar Planet. Sci. XVIII,* 360-361, Greeley, R., J.R. Marshall, and J.B. Pollack.