Short List of Potential Drilling Techniques for Drilling 200-m Deep Bore on Mars in Support of Subsurface Sampling

No.	System		Description of Sub-systems							
SL	Name of Drilling Method	Refs.	Rock and Soil Comminution	Drill Conveyance	Drill Cuttings Transport	Well Stabilization	Power Transmission	Bottomhole Power Conversion	PM&C[11] Downhole Telemetry	Downhole Thermal Management
Mechanical	**Overburden Drilling Systems**	**Drilling systems based on advancing a casing for borehole stabilization in unstable surface formations while or before drilling a smaller diameter hole to penetrate harder formation where these systems will not drill.**								
1	**Hollow stem auger**	[18]	Mechanical Rotary	Hollow stem auger sections	Auger + **Continuous Core**[10]	Casing While Coring	Mechanical Rotary	Auger Screw	DHT not supported	Auger Drill Stem to Formation
2	**Eccentric Reamer**									
A	Conventional **ODEX**[8]	[18]	Mech. Rotary/ Percussion	Drill Pipe + Special **ODEX™ Casing**[8]	Pneumatic Slurry	Casing While Drilling	Mechanical Reciprocation/Rotary/Pneumatic	Rotary Gouge Percussion Impact	DHT using **WLDHC**[13]	Air Cooling
B	Air Rotary	[4, 18]	Mechanical Rotary	T&C Drill Pipe + Special ODEX™ Casing[8]	Pneumatic Slurry	Casing While Drilling	Mechanical Rotary / Pneumatic	Rotary Gouge (Percussion Impact multi-cone)	Drill Stem Acoustic Telemetry	Air Cooling
C	Air Powered Pneumatic Motor	[4]	Mechanical Rotary/ Percussion	Continuous Tubing+Special ODEX™Casing[8]	Pneumatic Slurry	Casing While Drilling	Mechanical Reciprocation/Rotary/Pneumatic	Rotary Gouge Percussion Impact / Pneumatic Hammer/Motor	Telemetry Cable in Continuous Tubing	Air Cooling
3	**Dual Rotary Drilling**									
A	Conventional Mechanical Rotary	[18]	Mechanical Rotary	Drill Pipe + Special **LH Thrd.**[9] Casing	Pneumatic Slurry	Casing While Drilling	Mechanical Rotary/Pneumatic	RH Rotary Gouge Bit / LH Rotary Gouge Casing Shoe	DHT using WLDHC	Air Cooling
B	Sonic Drill Mechanical Vibrator	[7, 19]	Mechanical Percussion/ Rotation	T&C Drill Rods + Spec. LH Thrd.[9] Casing	Continuous Core	Casing While Drilling	Mechanical Reciprocation / Rotation	Percussion Impact Rotary Indexing Kerf Core Head	DHT not supported	Bit to Drill Rod to Rock and Core
C	Ultrasonic/sonic drill/corer	[17]	Mechanical Percussion	T&C Drill Rods + Spec. LH Thrd.[9] Casing	Continuous Core	Casing While Drilling	Mechanical Reciprocation	Percussion Impact Kerfing Corehead	DHT not supported	Bit to Drill Rod to Rock and Core
D	Air Diamond (Kerf) Coring	[4, 5, 18]	Mechanical Rotary	T&C Drill Rods + Spec. LH Thrd.[9] Casing	**Continuous Core**[10]/Pneumatic Slurry	Casing While Coring	Mechanical Rotary / Pneumatic	Rotary Gouge Core Head	DHT not supported	Air Cooling
4	**Wireline Retractable Drill/Casing Advancer**									
A	Conventional Mechanical Wireline Retractable	[18]	Mechanical Rotary	Casing Shoe w/Wireline Bit Replacement	Pneumatic Slurry	Casing While Drilling	Mechanical Reciprocation/Rotary/Electric/Pneumatic	Rotary Gouge Percussion Impact	DHT using Wireline	Air Cooling
B	Electric Motor with Air Cooling	[7, 8, 9, 10]	Mechanical Rotary	Umbilical **Wireline**[5] w/power cable	Pneumatic Slurry	Casing While Drilling	Electric / Pneumatic	Rotary Gouge (Percussion Impact multi-cone) / Electric Motor	DHT using Wireline	Air Cooling
C	Percussion Churn **Air**[2]	[1,18]	Mechanical Percussion	**Sandline**[5] drill under advancing casing	Scow Bailer / Bucket Auger	Casing While Drilling	Mechanical Reciprocation	Gravity Accelerated Impact w/Cable Wrap Indexing	DHT using Wireline	Bit to Cuttings to Formation
5	**Subterranean Moles**	**Suid circulation and cuttings disposal.**								
A	Percussion Mole	[JPL+RDS]	Mech. Rotary/ Percussion	Self propelled mole / umbilical	Repack cuttings behind the mole	Densified Wall and Re-packed Hole	Hydraulic or Electric	Percussion Impact Rotary Indexing / Electric Motor	DHT using cable in Umbilical	Mole to Cuttings and Rock (and Umbilical?)
Thermal										
6	**Rock Melting Drills**	**These are a family of systems based on partial or complete fusion of rock to produce a densified cast bore lining and excess melt removed by extrusion & solidification of small particles.**								
A	Conduction Melting	[7, 11, 12, 15]	Thermal Fusion	Continuous Tubing w/Utilities	Extruded Melt in Pneumatic Slurry	Densified and Annealed Glass	Electric / Pneumatic	Electric Heater / Fusion	Telemetry Cable in Continuous Tubing	Air Circulation and Expansion
B	EM Melting (LASER and Microwave)	[7, 11, 12]	Thermal Fusion	Continuous Tubing w/Utilities	Extruded Melt in Pneumatic Slurry	Densified and Annealed Glass	Electric / Pneumatic	EM Radiation Generator / Fusion	Telemetry Cable in Continuous Tubing	Air Circulation and Expansion
C	Electric Arc and Plasma Melting	[7, 11, 12]	Thermal Fusion	Continuous Tubing w/Utilities	Extruded Melt in Pneumatic Slurry	Densified and Annealed Glass	Electric / Pneumatic	Spark or Arc Plasma Heater / Fusion	Telemetry Cable in Continuous Tubing	Water Circulation
SL	**Name of Drilling Method**	**Refs.**	**Rock and Soil Comminution**	**Drill Conveyance**	**Drill Cuttings Transport**	**Well Stabilization**	**Power Transmission**	**Bottomhole Power Conversion**	**PM&C[11] Downhole Telemetry**	**Downhole Thermal Management**

Footnotes

1 Mud implies **liquid** drilling fluids including water, natural mud, bentonite base mud, or polymer-based mud.

2 Air implies Martian atmosphere primarily **CO_2** at a uncompressed pressure of 800 Pa + ~200 Pa.

3 Motor and/or Hammer implies downhole transmitted power conversion to **rotary and/or reciprocating** mechanical

4 **T&C** = threaded and coupled segmented drill stem. **Drill steels** are hollow, thick-walled steel rods designed to convey high reciprocating compressive loads from the surface to the bit. **Drill pipe** has externally/internally upset tool-joint-connection design for high tensile and torsion loads and a pipe diameter of 0.2 to 0.7 times the bore diameter. **Drill rods** have flush-joint external connections and a pipe diameter > 0.7 times the bore diameter that is designed for high speed rotation obtaining laterally significant support from contact with the bore wall. **Push rods** are 3 to 5-ft (1 to 1.7-m) long, threaded and coupled solid rods or heavy wall steel tubes. **Continuous Tubing** is coiled or reeled tubing that is inserted and retracted from the bore much like a wireline and can be inserted and retracted with out cessation of circulation, power transmission, or telemetry. **Umbilical** are flexible wirelines or tethers with telemetry and power cable, and hydraulic/pneumatic hoses.

5 A **sandline** is a structural steel wire cable with no copper or fiber optic telemetry. A **wireline** is a telemetry (wire or fiber optic) cable wrapped inside a structural steel armor cable so that the entire cable is self-supporting in a deep hole.

6 **TBD** = to be determined. Commercial system or prototype technology is unknown or does not exist or effect of drilling method on hole stability is not obvious or known.

7 **w/Utilities** = with utilities installed inside of the tube or cable that may include telemetry or fiber optic cables, and electric power cable, and/or hydraulic or pneumatic tubing.

8 **ODEX™** = overburden eccentric drilling. Commercial advanced casing-while-drilling system for shallow unconsolidated and unstable formations [1]. The system uses an under-reaming bit that can be run and withdrawn through the casing. The bottom of the casing is tipped with hard facing and the casing is advanced with percussion.

9 **LH Thread**. = Left hand threaded casing. Casing is advanced with a dual rotary table that **Right Hand** rotates a conventional drilling system with an eccentric, extractable, under-reaming bit inside a **Left Hand** rotating casing string with a rotary drilling shoe on bottom.

10 **Continuous Core** with thin wall T&C drill stem, drill rods or hollow stem augers supports wireline core retrieval.

11 **PM&C** = process monitoring and control – Long list addresses downhole telemetry presently supported or conceptually supported in the system concept proposed

12 **DHT** = downhole telemetry support through or in drill stem. Telemetry for some systems is not supported in commercial or prototype systems that we are aware of.

13 **WLDHC** = wireline downhole connection. This is a wireline that is run through a top drive rotary swivel or surface tubing thruster and through the inside of a T&C drill stem or push rod after the bit is set on the bottom of the hole. It is then plugged into the bottom-hole assembly using wet-connect technology that would be a dry connection in air drilling or thrust boring.

Reference List

1 Chugh, C. P., ***Manual of Drilling Technology,*** Rotterdam: A.A. Balkema, 1987.
2 Moore, P. L. et al., ***Drilling Practices Manual*** , Petroleum Publishing Co., Tulsa, OK, 1974.
3 Bourgoyne, A. T., K. K. Millheim, M. E. Chenevert, and F. S. Young, ***Applied Drilling Engineering*** , Society of Petroleum Engineers, Richardson,TX, 1991.
4 Maurer Engineering Inc. Report, "***Underbalanced Drilling and Completion Manual - DEA-101,*** Phase 1," Maurer Engineering, 1996.
5 Heinz, W. F., ***Diamond Drilling Handbook - First Edition*** , South African Drilling Association, Johannesburg, Republic of South Africa, 1985.
6 Maurer, W. C. and W. C. Herben, "Deep Earth Sampling System – Phase 1, Final Report," National Science Foundation, ISI –8960064, 1990.
7 Eskin, M., W. C. Maurer, and A. Leviant, ***Former-USSR R&D on Novel Drilling Techniques*** , Maurer Engineering, 1995.
8 Abyzbayev, B. I. et al., "Electro drill provides alternative drilling system," Oil & Gas Journal, Feb. 9, 1998.
9 Newman, K. R. and L. R. Stone, "Electric Drilling Motor for Coiled Tubing Drilling – Phase 1, Final Report", Gas Research Institute, CN. 5095-210-3342, 1995.
Turner, D. R., T. W. R. Harris, M. Slater, M. A. Yuratich, and P. F. Head, "Electric Coiled Tubing Drilling: A Smarter CT Drilling System," SPE 52791, SPE/IADC Drilling Conference, Amsterdam, Holland, 9-
10 11 March, 1999.
11 Maurer, W. C., ***Novel Drilling Techniques*** , Pergamon Press, London, 1968.
12 Maurer, W. C., ***Advanced Drilling Techniques*** , Petroleum Publishing Co., Tulsa, OK, 1980.
13 Kolle, J., M. Marvin, and M. Celich, Coiled Tubing Drilling with Supercritical Carbon Dioxide - Phase 1 SBIR, Final Report, USDOE SBIR Report, 1999.
14 Williams, R. E. et al., "Advancements in thermal spallation drilling technology," Los Alamos National Laboratory Report No. LA-11391-MS, 1988.
15 Hanold, R. J., et al., "Rapid Excavation by Rock Melting Drill – LASL Subterrene Program," LA-5979-SR, Los Alamos National Laboratory Report, 1977.
16 National Research Council, ***Drilling and Excavation Technologies for the Future*** , National Academy Press, Washington, D. C., 1994.
17 JPL's NDEAA Ultrasonic Drilling Homepage http://ndeaa.jpl.nasa.gov/nasa-nde/usdc/usdc.htm