

SERCEL: 引领当代物探装备技术进步

SERCEL Advances the Up-to-date Geophysical Equipment & Technology

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SERCEL是全球最大的地球物理服务公司—法国地球物理公司(CGGVeritas)的全资子公司,负责陆地、海洋、地面和井筒地震勘探装备的研发、生产和销售。SERCEL公司依托CGGVeritas这个最大的地球物理应用平台,以服务全球的油气勘探业务为己任,长期致力于地震勘探核心技术和关键装备的研发和推广,始终站在世界物探科技的前沿,引领着全球物探装备技术的进步。SERCEL公司具有最完整的产品线,包括:震源、检波器和记录系统,涵盖了陆地、滩海过渡带、深海和井筒地震勘探的所有领域,其产品不仅广泛应用于常规的石油天然气勘探开发,而且成功应用于新兴的、国家重点发展的油气勘探业务如页岩气、致密砂岩气和煤层气等非常规油气勘探。

本期作者将主要介绍SERCEL公司的陆地地震勘探最新装备和技术,

主要包括:428XL系列地震采集记录系统、DSU1/DSU3单分量和三分量数字检波器、NOMAD系列大功率可控震源、GeoWaves/MaxiWave系列三分量VSP井中地震采集设备等,这些装备和技术几乎涵盖了陆上地震勘探的所有领域,代表了当今地球物理勘探行业的最新发展成果。

428XL:

新一代地震采集系统

428XL是SERCEL公司于2005年推出的全数字遥测地震采集系统。它兼容408UL的地面设备,大线和交叉线的传输速率在2毫秒采样时分别提高到16M和100M,单线实时传输带道能力达到2,000道,同时采集站(FDU)的重量和功耗得到大幅降低。采用基于MEMS技术的数字检波器(DSU)使得428XL成为单个检波点(RP)平均重量最轻的地震采集系统(每检波点仅1.8公斤,包括电瓶、

SERCEL, a subsidiary of CGGVeritas - the largest geophysical services company around the world, is specialized in the development, production and sales of onshore and offshore, surface and downhole seismic exploration equipment. SERCEL, relying on the largest geophysical application platform of CGGVeritas, is aimed at serving the global oil and gas exploration and production business, and has been for long time dedicated to research and development and promotion of core seismic exploration technologies and key equipment. SERCEL has always stood ahead of global geophysical technology and led advancement in seismic acquisition equipment. SERCEL has the most comprehensive product line, covering all technologies from sources, recorders and receivers in all environments from land, transition zone to seabed, deep sea and borehole. These seismic equipment are not only used in conventional oil and gas exploration and development, but they have also proved to be very useful in targeting the unconventional reservoirs such as shale gas, tight gas and coal bed methane to which major countries rely for their future development.

In this article, the author describes the latest land seismic acquisition equipment of SERCEL, including: the 428XL high capability recording system, the Digital Sensor Unit (DSU) which is a single or three component (3C) digital accelerometer, the NOMAD series of high-power vibrators and different long array 3C digital borehole

检波器、电子单元和大线等)；DSU和FDU均采用采集链结构，一个采集链有几个(一般1~6个)DSU或FDU，大大减少了接头数量，提高了可靠性。428XL的全数字传输仅依靠电缆内的两对线，从DSU和FDU开始经过大线上的电源站(LAUL)、交叉线上交叉站直达大线接口(LCI)。大线接口(LCI)与采用TCP-IP协议的交叉线具有相同的最大道能力，大线接口与主机相连，而作为服务器的主机，采用了服务器-客户机结构，这样就使428XL的采集能力随大线接口(LCI)和交叉线的数量增多而线性增长，实现从100道到10万道的采集能力，满足任何2D/3D地震采集作业的需求。客户端可以在仪器车内或在远离仪器车的营地、办公室等处，只要有因特网服务(通过卫星或以太桥等方式)既可实现远程实时采集数据显示，又可以对采集质量进行监控：包括仪器、检波器、震源状态所有内容，极大地提高了采集质量的监控管理水平。

428Lite(如图1)就是一款以笔记本电脑做主机的、具有100道至2,000道采集能力的、以炸药激发为主的便携式地震采集系统。整个系统重量只有3.5公斤，无需发电机供电(只用12V电瓶即可对主机供电)，无需专用仪器车。428LITE基本配置包括一台笔记本电脑，一个交叉站，一个网络集线器，一台GPS，根据勘探要求可以配置一台



图1 428XL-LITE便携式地震采集系统

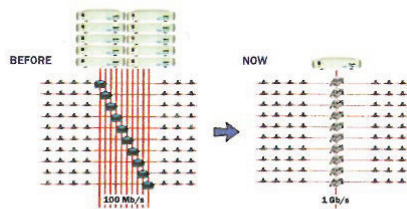


图2 具有10万道采集能力的428XL地震采集系统：从常规(100Mbps)交叉线传输到千兆(1Gbps)交叉线

绘图仪，一台NAS存储器。因此，428LITE的轻便性使其能够满足2D或小3D炸药震源项目，适合丛林和山地地震作业，可以大幅降低地震队后勤保障运输成本，减少HSE压力。因为248Lite具有与UNITE无线系统同样的优点，SERCEL最近推出了UNITE-Lite，它结合了二者的优点使生产效率又得到进一步提高。428Lite一经面世就受到石油和煤田地震队的广泛欢迎，目前已经有100多台套428Lite采集系统应用于石油和煤田地质勘探单位。

对于当前流行的宽方位、高密度地震采集，428XL系统的带道能力可以随采集要求而随时扩展。一个采用常规交叉站(LAUX)的光纤交叉线的传输速率为100Mb，具有实时采集1万道(2ms采样)的能力。然而快速发展的高密度空间采样技术对排列片的大小提出更高的要求，即：满足几个交叉线同时实时传输(多

tools(GeoWaves & MaxiWave)。These seismic acquisition equipment cover almost all areas of onshore seismic exploration and reflect the most advanced technology of the current geophysical exploration industry.

428XL: the most reliable and flexible high capability seismic recording system

428XL is a single telemetry (one digitizer per channel) seismic recording system launched by SERCEL in 2005 to enhance the capabilities of the previous very successful 408UL system to which field equipment is compatible. To increase channel capability transmission rates have been improved on both lines (16Mbps or 2000 channels real-time @2ms) and transverse (100Mbps or 10,000 channels real-time @2ms). At the same time the weight of the equipment like the Field Digitizing Units (FDU) as well as its power consumption have been reduced. Thanks to the replacement of the heavy geophone strings by MEMS-based accelerometer within single digital sensors, 428XL has been able to provide the industry with the lightest possible receiver point available on the market (1.8 kg /RP @15m all included: battery, sensor, electronics & cable). These Digital Sensor Units (DSU) or the FDU's that are connected to the geophones have their electronics integrated to the telemetry cable. This assembly called Link is made of several RP's (one to six) without connectors (except at both ends) to improve line reliability. Full digital transmission of thousands of channels via only two pairs of wire from the sensor (DSU) to the recorder is performed via power units (LAUL) on the lines and crossing units (LAUX) on the transverse.

The Ethernet transverse based on a TCP-IP protocol is connected to Central Unit via a Line Computer interface (LCI) that has the same maximum capability as the associated transverse. The Central Unit itself is based on a client-server architecture running under Linux that offers a great scalability to adapt its configuration and price to any spread from 100 to 100,000 channels by adding LCI's and transverses. The client may be local or at any remote location (basecamp, client or contractor office...) providing there is an internet connection with the recorder (satellite, Ethernet bridge). With such capability not only seismic data can be displayed in real-time but also all other Quality Controls (instrument, sensor,



图3 428XL配套的系列数字检波器

达10个100M交叉线，如图2)。当排列在一个工区内反复滚动时，上述排列配置会达到极限，因此SERCEL研发了基于以太网技术的光纤千兆交叉线，它达到千兆传输速率，具有实时采集10万道（2ms采样）的能力（图2）。上一代常规交叉站可以作为次一级交叉线兼容在采用千兆交叉线的排列内，实现多路径传输。这种光纤千兆交叉线包括几个特殊设备：光纤交叉站（LAUX-G），光电转换接口（TFOI-G）和大线接口（LCI-G）。与上一代交叉线相似，可以同时使用多个光纤千兆交叉线（如两个千兆交叉线即可达到2ms采样20万道实时传输的能力），这意味着通向100万道采集能力的道路已经铺就，可以满足未来5~8年后（2017~2020）对这种大规模排列配置的需求。需要注意的是：主机服务器的处理能力，包括内存和存储，也要随着LCI-428接口个数的增加而增加，可喜的是由于基于PC技术的工作站的快速发展，这种PC工作站已经可以作为业内服务器的成熟选择。

配套检波器类型最多的地震采集系统 基于MEMS技术的DSU数字检波器与428XL系统的集成不仅实现了从信号接收到记录的全数字传输，而且也使不改变记录系统的任何配

置，就能实现点接收、高密度多分量采集。这使得428XL成为目前业界唯一同时既支持模拟检波器串采集、又支持单分量数字检波器和三分量数字检波器的地震采集系统。目前，多数地震勘探仍然使用模拟检波器串，而新兴的多分量地震就要求使用三分量（3C）数字检波器实现全波场接收，包括纵波（PP）和转换（PS）横波。甚至某些工区会要求混合使用常规单分量的FDU采集站和三分量的数字检波器进行无缝隙的接收。

基于MEMS技术的数字加速度检波器是SERCEL公司20多年研发努力的结晶，已经形成完整的数字检波器系列：单分量数字检波器DSU1、三分量数字检波器DSU3，以及可埋置型三分量数字检波器DSU3BV和自定位型三分量数字检波器DSUGPS。其中，DSU3BV的埋置深度达到15米，DSUGPS的定位精度达到+1m/，方位+3°，SERCEL数字检波器家族可以满足在不同地表条件下单分量和三分量高密度数字地震采集的需求（图3）。

SERCEL基于MEMS技术的加速度数字检波器在信号保真度和频率响应特性方面具有常规模拟检波器所无法比拟的优势：它能够直接数字信号输出，在地震频段（0~800HZ）其失真度仅为0.0032%（-90db），其频率响应为恒幅（无衰减）和零相移；DSU的性能不随温度/时间变化的影响，能够避免外界电磁干扰；同时，相对于重力矢量所做的直流

vibrator QC's) are made remotely available to acquisition supervisors.

As an example of scalability of the 428XL system the 428-Lite (Figure 1) is a portable seismic acquisition system for impulsive surveys recorded from 100 to up to 2000 channels. It weighs less than 5kg and it may work from a 12V battery. The whole system basically consists of a laptop computer as (client and server), a crossing unit (LAUX), a GPS for synchronization, and a break-out Lite box. If a generator is available a plotter and a NAS disk can also be connected via an Ethernet switch. Therefore, the portability of 428-Lite makes it an ideal recorder for 2D and small 3D surveys from impulsive source like those often performed for coal mines. It is also very suitable for difficult environments like jungle and mountainous seismic operations for which it is able not only to greatly reduce the logistics costs but also decrease HSE exposure. Since the 428-Lite provide the same advantages on the recorder side as the UNITE cableless system for field equipment, SERCEL recently launched the UNITE Lite that capitalizes on the benefits of both equipment to greatly improve the production efficiency. Today, 428-Lite is widely accepted by contractors working for oil and mining exploration in difficult terrain conditions, and there are more than 100 systems on use.

With regard to the current trends towards wide azimuth high-density seismic acquisition, at least in open areas, the channel count capacity of 428XL system can be expanded whenever required for acquisition. One conventional 428XL transverse using copper wires or optical fiber has the transmission rate of 100 Mbps and the real-time capacity of 10,000 channels real time @2ms sampling rate. However, the fast growing requirement in spread size and dense spatial sampling made it necessary the simultaneous use of several transverses (up to 10 x 100Mbps; Figure 2) to be able of real-time data transmission. Such configuration adds constraints when the spread needs to be rolled to progress in the block to be surveyed. This explains why SERCEL did develop an optical fiber Giga transverse also based on Ethernet to be able to recover up to 100,000 channels real-time @2ms (1Gbps; Figure 2). It is not compatible with

标定使得DSU具有了自动倾角校正功能。DSU数字检波器是单点接收的理想检波器，首先它不仅能避免常规组合接收的组合效应对高频信号的影响，其次，也能避免组合检波对方位角各向异性属性的滤波效应。然而，在低信噪比地区，因为单点接收不能提高信噪比，所以单点数字检波器不能替代常规模拟检波器串。在常规组合基距范围内用几个数字检波器来替代模拟检波器串是必须的，这样可以无假频的记录规则噪音，提高覆盖次数从而可以通过处理手段提高环境噪音的压制效果。

随着高精度地震勘探的发展，利用428XL系统进行数字检波器单点接收高密度地震勘探的优势日益明显并被业界所接受。新疆油田在某油区采用428XL系统利用DSU1数字检波器进行单点、小道距高密度空间采样地震勘探生产表明：采用高密度

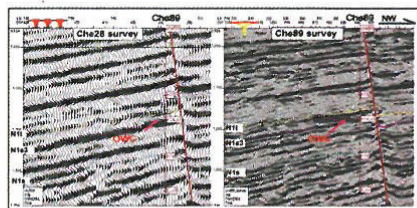


图4 428XL常规三维地震(左)与数字检波器高密度三维(右)效果对比

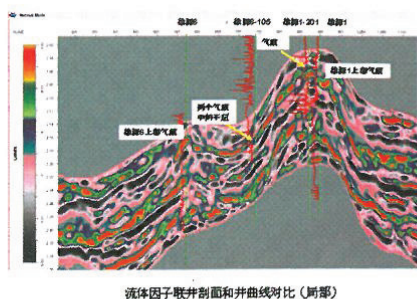


图5 PP-PS联合反演流体因子属性联井剖面 and 井曲线对比

数字检波器三维剖面能够提高垂向分辨率和信噪比，并达到清晰地反映出某井油藏的油水界面(图4)的效果。

由于MEMS芯片体积小、重量轻，灵敏度高，可以加工成检测全波场的三分量检波器(DSU3)，从而可以避免以往用多个模拟三分量检波器进行多分量采集所造成的极性误差、分量错误等问题，通过PP和PS联合勘探提高油藏预测的精度。

2004年10~12月，大庆物探公司在徐深气田采用SERCEL公司的DSU3三分量数字检波器进行了二维三分量地震勘探。本次勘探的目的层是深部火山岩油气藏。由于天然气的存在，使得常规纵波资料在气藏层段速度变小，利用常规纵波波阻抗反演方法预测气藏存在多解性，因此给精细气藏描述带来一定的困难；而横波速度基本不受气层的影响，综合应用纵波和横波资料可以极大地提高油气藏描述的精度。

基于PP波和PS波叠前时间偏移道集的纵、横波联合反演和储层预测结果表明：XS1井和XS6井与联合反演的结果(如图5)相当吻合，有助于空间上精细刻画气藏极其泥岩隔层。徐深气田多分量勘探的应用效果表明：纵、横波速度比 V_p/V_s —伽玛参数是研究气藏的有力工具，从而进一步证明纵、横波联合勘探是提高油藏预测精度、减少储层预测的多解性，也是提高油气藏描述精度的有效方法。

the previous conventional one that can be used only as secondary transverse like for multi-path data recovery. It is based on specific new equipment for crossing unit (LAUX-G), optical-to-electrical conversion (TFOI-G before and after each LAUX-G) and Line Unit Interface (LCI-G). Like for the previous transverse it is possible to use several of them (e.g. two Giga transverses to transmit up to 200,000 channels real-time @2ms) which mean that the road toward a one Million channel configuration is paved even if such large spread configuration should not be on demand before at least five to eight years (2017-2020). It should be noticed that the server processing, memory and storage capability must also increase with the quantity of LCI interfaces which is made possible thanks to the rapid progress of in the PC-based workstation made available by the industry.

428XL : the recording system compatible with the most different types of sensors The integration of the MEMS-based Digital Sensor Unit (DSU) within the 428XL acquisition system not only provides a full digital telemetric transmission from the sensor to the recorder, but also made it possible point receiver, high-density, multi-component acquisition without any change in the recording equipment. Thus, 428XL has become the only hybrid system in the industry supporting without modifications both analog geophones and/or digital accelerometers. At present, most seismic exploration projects still use conventional analog string of geophones, while the emerging Multi-Component (MC) seismic requires three-component (3C) digital sensors, to record the full wavefield including compressional (PP) and converted (PS) shear waves. In some surveys made from fixed spreads a mix of FDU's connected to 1C-geophones and of 3C-DSU's was seamlessly recorded by the 428XL.

MEMS-based accelerometers as produced by SERCEL are the result of more than 20 years of Research & Development effort. In complement to the lightweight one component DSU (DSU1; Figure 3) three-component DSU family includes the conventional DSU3, a version that can be buried down 15m depth (DSU3BV), and the self-positioning (+1m) / orienting (+3°)

业界惟一采用有线遥测和无线传输相结合的系统 Unite无线系统与428XL有线系统的集成（同样的电子单元、同样的软件、同样的QC手段等）使得混合排列的428XL系统能够更容易适应各种复杂采集地形，保持记录数据的一致性，输出单一的SegD文件。

随着地震勘探领域逐渐向人口密集的城区、人口稀少的丛林和复杂山地转移，各种障碍物如居民小区、工厂设施、河流、山涧等地形障碍造成的常规地震采集问题：电台通讯不畅、排列中断、数据传输困难和质量控制困难等，严重影响着地震数据的质量和作业效率。长期以来428XL系统为了克服上述问题，发展了各种遥测支持技术（如：无线以太桥和激光中继等）和多路径传输技术（如：次级交叉传输、绕线和蛇形排列等）；然而，以当今的技术观点出发，克服上述问题的最有效方式就是采用UNITE无线采集站来补充428XL有线遥测系统（图6），某些情况下，非常复杂的地形只能使用无线系统。从而保证地震数据空间分布的连续性和完整性，真正实现无障碍三维地震采集。

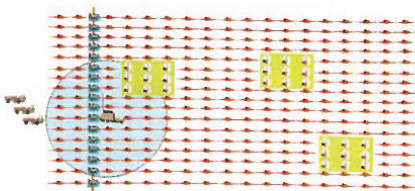


图6 428XL系统有线遥测传输和UNITE无线系统混合使用效果图

UNITE无线采集系统的RAU无线采集站能自主地进行连续地震采集，并能对地震数据、检波器和仪器状态进行监控。它集成了GPS和WIFI技术，采用GPS技术进行系统同步和授时，采用WIFI技术进行采集参数遥控设置、数据远程回收和实时质量监控，而采集不受影响；在蜂窝存取节点（CAN）半径（1公里）范围内的RAU无线采集站通过CAN天线（一般与交叉站相连）实时把数据传输到主机。内部锂离子电池支持RAU连续自主采集（达到3天，如果被盗可以工作10天），外接18安时铅酸电瓶时，RAU可以自主采集4个星期（按每天12小时连续记录），即使数据回收后，原始地震数据在RAU内的循环存储器中可以驻留最少一个月的时间，从而有足够时间可以确保最终的地震数据完全正常。

SERCEL提供与428XL系统配套的全系列的RAU无线采集站，包括接常规检波器串的标准单分量无线采集站（RAU）；接三个检波点或三分量模拟检波器的无线采集站RAU-3（3C），和接特定三分量MEMS加速度检波器（DSU3SA）的无线采集站RAU-D。

NOMAD系列可控震源： 高效率地震理想激发源

随着地震勘探目标日趋复杂，对地震数据对称空间采样的要求越来越高，即：炮线和检波线的参数相同且互相垂直；这就要求在采用

DSUGPS thanks to a combination of two GPS antennas.

All these DSU's display incomparable superiorities to conventional analog geophone in vector fidelity and frequency response characteristics thanks to: their flat and linear amplitude and frequency response (0-800Hz), their calibration at DC with respect to the gravity vector that is used for automatic tilt correction, their low distortion (0.0032% or -90 dB), their insensitivity to temperature/aging, and their immunity to EM interferences. DSU's are ideally suited for single-point receiver acquisition that prevent from the detrimental effects of the geophone arrays like the intra-array statics detrimental to the high frequency preservation or the directional filtering that may bias the detection of the azimuthal anisotropy. However in a noisy environment a single DSU cannot replace a full string of geophone to improve the Signal-to-Noise. It gets necessary to plant several DSU's within the previous array length to be able to record an unaliased organized noise and to increase the fold coverage necessary for the ambient noise reduction. Xinjiang Oilfield applied the 428XL system to an oil field for single point dense 3D acquisition: sections acquired with DSU1 at a spacing lower than the previous geophone string length clearly evidence the oil-water contact (OWC) due to the improved vertical resolution and S/N (Figure 4).

Due to its small size and easy integration with electronics, MEMS chip can easily be assembled into three-component DSU3 avoiding the many polarity or component errors that may occur when connecting triphones to the three different digitizers (one FDU per component). By recording the combined PP and PS-waves they have improved reservoir prediction accuracy.

Daqing Geophysical Company carried out 2D-3C seismic exploration in 2004 by using DSU3 in Xushen gas field. The target of the exploration was a deep volcano-clastic gas reservoir. The P-wave velocity becomes lower due to the existence of natural gas, while shear wave velocity is basically not affected. Thus, a comprehensive use



图7 90, 000磅出力的NOMAD90可控震源在作业中

多组震源（2到32组）激发时，震源激发效率必须有较大的提高，才能满足使用428XL和电控箱体（VE464）高效作业方式的要求。采用高效可控震源作业方法，必须压缩两个连续扫描间的周期，同时结合轮替扫描（交替扫描或滑动扫描）和同时扫描（如DSSS扫描等）作业方法。这样，在开阔地表条件下，可控震源的日生产效率可以达到20,000个震点以上。在复杂地表时，可以采用独立同时扫描方式，即：根据地形把激发模版分成若干部分（可以和震源个数一样多），428XL主机借助GPS授时始终连续记录，并保持与每一个震点同步，大大减少主机与震源间的无线通讯联络。

为了达到单点高密度激发，而又不增加地震队可控震源的数量，必须使用重型可控震源（如Nomad65）和超级重型震源（Nomad90）进行作业（图7）。Nomad系列可控震源采用强化的机械和液压系统，能够提供宽频扫描，为了激发低频能量，提高了液压流量和行程，使低频端从1HZ开始扫描。为了激发高频能量，提高了平板的刚度和伺服阀的响应，高频端扫描频率达到250HZ。这些技

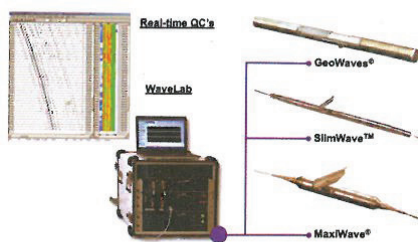


图8 SERCEL三分量井下VSP工具和Matlab记录仪

术措施不仅使得地震信号的分辨率得到提高，而且减少了谐波畸变的影响，有益于最终地震成像精度的提高。

自2003年推向市场以来，Nomad65可控震源就具备多种气候和地形配件可供选配，如：适合沙漠和雪地作业的履带，适合极低温环境（-30℃或-50℃）的冬季包，以及城镇作业的隔音罩等。作为高密度可控震源作业的标准装备，在用的Nomad65已经有700多套，主要分布在俄罗斯、北美和中东地区，少量在中国的物探公司使用。SERCEL利用在Nomad65可控震源上的开发经验，成功推出了Nomad90超级重型可控震源，它的峰值出力（减少扫描时间）更高，达到90,000磅，扫描频带范围更宽，地球物理性能更好。

适合不同井况的新型 数字三分量VSP接收系统

垂直地震剖面（VSP）技术是油气勘探新区获得突破，老区深入挖潜所必不可少的关键技术。由于VSP采用井下接收，检波器接近反射点，降低了近地表吸收衰减对资料的影响，因此，VSP地震资料具有高

of PP & PS-waves will greatly improve the precision in gas reservoir description. After joint inversion of the prestack time migration PP & PS gathers, different elastic parameters were defined that match the well logs at XS1 and XS6 and helps to correlate the gas and shale layers between these wells (Figure 5). The result of multi-component exploration in Xu-Shen gas field confirms that 3C exploration is an effective method to improve the precision and reduce the non-uniqueness of reservoir characterisation.

428XL: the perfect combination of cable & cableless RP's within hybrid spreads The integration of the Unite cableless system within the 428XL cable system (same electronics, same software, same processes and same QC's) makes it possible the use of hybrid spreads that may more easily adapt to various terrain configurations while keeping the benefit of recording consistent seismic data output as a single SegD file.

With the gradual shift of seismic exploration towards densely populated areas, more difficult access terrain or environmentally sensitive regions, conventional seismic acquisition is facing lot of difficulties to layout the spread across the many obstacles, to communicate via radio with the source and the field operators and to transmit data and QC's via the lines and the transverse. This of course decreases operating efficiency. If for the 428XL cable systems solutions have been developed for long time using multiple support telemetry (e.g. Ethernet bridge or laser) and multi-path telemetry (e.g. secondary transverse, line snaking or detour), it is obvious today that the most efficient way (except for transverse) from an operational point of view is to complement cable lines with FDU's by the UNITE Remote Acquisition Units (Figure 6). Sometimes the terrain configuration gets so complicated that only cableless units are used

These RAU's are autonomous recorders performing continuous seismic acquisition and able to QC data, instrument and sensors. They integrate GPS for synchronization and WiFi for remote seismic data and QC'

信噪比、高分辨率和丰富的运动学和动力学特征等优点，可以精细研究层间多次波的产生、P波到S波的转换等现象，是建立地下地层结构与地面地震之间精确标定关系的桥梁。随着微地震监测、井间地震、四维地震等针对油藏目标地球物理勘探技术的日益发展和成熟，VSP技术的应用前景必然越来越广阔。

SERCEL公司研发VSP井下工具已有50年的历史。自2000年以来，SERCEL向市场提供全套的三分量多级数字井下工具，以适应不同的井眼条件，满足不同成像要求。这些VSP工具全部采用普通7芯测井电缆，具有实时传输速率高（从2.5Mbps到4Mbps不等），多种采样率（最小采样率达到0.25ms），高达100级三分量接收等特点。全部使用WaveControl软件实现井下设备作业监控和测试，采用基于Windows的Wavelab记录系统（图8），可与428XL和VE464保持同步，进行3D地面地震和井间地震联合勘探。

SlimWave（图8）具有24级三分量接收能力，适合小井眼作业，借助于井下拖拉机时，可以在水平井作业。在用的SlimWave已达到200级，主要用来进行微地震检测。GeoWaves（图8）具有32级三分量接收能力，适合裸眼井和套管井作业，允许60°井斜偏差，抗恶劣井下环境（耐高温180℃，耐压22,000psi）。在用的GeoWaves已达到300多级，主要集中在中。MaxiWave（图8）具有100级

s harvesting on the field while acquisition is not discontinued. Within the radius (up to 1 km) of the Cell Access Node (CAN) antennas which are connected via Ethernet to the recorder or to the crossing units (LAUX) this data transmission is performed in (near) real time as for cable. Each of these RAU's includes an internal Lithium-Ion battery with a limited autonomy (3 working day recording, about 10 day detection in case of lost or stolen unit). Connected to an external 18 Amp. Hr. external lead-acid battery that can be hot swapped the RAU autonomy gets above four weeks of 12h/day continuous GPS time stamped recording. Even when these data are harvested they stay stored in a circular buffer for at least one month before to be erased providing sufficient time to be sure that data have been properly stored as SegD files.

A full range of RAU has been made available in order to be able to provide the same capability as for the 428XL cable system: the standard RAU (1C) manages the conventional strings of geophones; RAU-3 (3C) can be used to record three RP's or triphones; RAU-D is to be connected to a specific 3C MEMS accelerometer (DSU3SA).

The NOMAD family vibrators: an ideal source for high productivity and wide band Vibroseis

For 3D land acquisition optimal spatial sampling it is recommended to perform symmetric sampling which requires the same geometry for the source lines than for the receiver lines both being perpendicular each other. This call for a large increase in productivity on the source side that becomes possible if several fleets of vibrator are used (from 2 to 32) in conjunction with advanced shooting methodology as made available by the 428XL and the Vibrator Electronics (VE464). With these high productivity Vibroseis methodologies the cycle time between two successive sweeps gets reduced. By combining alternate (like Flip-Flop or Sleep-Sweep) and simultaneous (like Distance Separated Simultaneous Sweeping) operations,

the daily productivity in operations in open terrain may reach 20,000 Vibrating Points (VP's) per day. In complex terrain, a methodology like the Independent Simultaneous Sweeping (ISS) requires to split the active template in several areas (as many as the number of vibrators) which relative dimensions depend also on the local conditions. Radio communications with the Central Unit often difficult in such context is not mandatory: using GPS timing for the continuous recording by the 428XL as well as to stamp the time break of each VP's both get synchronized.

Since the number of vibrators available on a crew is limited and to preserve the amount of energy emitted per square kilometer it becomes necessary to use heavy (e.g. Nomad 65) or super heavy (e.g. Nomad 90) vibrators (Figure 7) within fleets having a limited number of units (often a single vibrator to maximize the number of groups and to be able to perform point acquisition). In addition Nomad family vibrators have been designed with enhanced mechanical and hydraulic characteristics to be able to widen the frequency bandwidth. To emit the Low Frequencies (LF from 1Hz) the displacement of the mass (stroke) has been increased together with the hydraulics flux made available. For the High Frequencies (HF up to 250Hz depending on terrain conditions) the rigidity of the baseplate has been improved as well as the response of the valves. The benefits are not only higher vertical resolution but also less harmonic distortions, both contributing to seismic imaging enhancement.

The Nomad 65 marketed since 2003. It is made available with many options depending on terrain condition like: tracks for sand or snow, winterization for low temperatures (down -30°C or -50°C) or soundproof cover for acoustic isolation in town. With more than 700 units in operation (mainly in Russia, North Africa and Middle East, but also with some in China) this vibrator has become a standard for high density high productivity Vibroseis. Nomad 90 benefits from all experience gained with Nomad 65 to provide enhanced performances thanks to higher hydraulic peak force (thus reducing the sweep time) and more powerful LF and HF sweeps

三分量接收能力，井下最长排列可以达到2000米，如此长的井下排列，可以大大缩短3D VSP的作业周期。得益于内置马达离合器，在井下仪器遇阻或故障时，只需在地面关闭系统电源，所有井下仪器的推靠臂自动收拢。在用的MaxiWave系统数量已达到500级9套，分布在全球各大地球物理公司。

综上所述，物探装备技术的不断进步推动着地震勘探技术从常规三维勘探向高分辨率、高密度、宽方位和多分量纵、横波联合勘探技术发展；在提高复杂构造成像和油藏描述精度的同时，大幅提高生产效率，降低勘探成本。SERCEL公司长期致力于地震记录系统、地震震源和传感器技术的研发，坚持以科技进步作为公司的发展方向，引领着全球物探科技的进步和发展。作为全球最大的地震采集装备制造制造商，SERCEL始终与全球的地球物理公司一道共同迎接各种各样的技术挑战。

SERCEL公司高度重视中国客户的各种需求，以服务于中国的地球物理公司为己任，不断强化售后服务和技术支持，秉承一贯的服务承诺，即“无论何时何地，SERCEL的售后服务48小时全球到达和服务热线24小时畅通”，大力支持并积极推动中国的地球物理勘探公司在中国乃至全球业务的广泛开展。SERCEL公司北京代表处全体同仁真诚祝愿中国的地球物理勘探事业不断进步，蓬勃发展。

3C digital multi-level downhole seismic arrays for different environments

The Vertical Seismic Profiling (VSP) technology is a key technology necessary for oil & gas exploration and production. By clamping long downhole array of 3C receivers in the borehole, it get possible to image the near well environment with high signal-to-noise ratio, much better vertical resolution due to the proximity to the reflections and improved time-to-depth calibration. In addition, the levels at which significant internal multiples and/or the P-to-S conversion occur are directly detected. These VSP tools have other applications at the reservoir levels like for monitoring micro-seismic activity and for cross-hole tomography and imaging when the source is activated in the borehole. All these downhole methodologies have important application in mature fields where many well already exist and where accurate correlations between (thin) reservoir layers become more important to improve oil & gas recovery.

SERCEL develops VSP tools for forty years. Since the early 2000's it markets a full range of 3C digital multi-level downhole seismic arrays, each one adapted to different borehole environments and/or seismic imaging constraints. Their common characteristic is that they used the standard logging cable (7 conductor) and real-time high speed telemetry (from 2.5 to 4Mbps) to recover up to 100 3C levels made in Titanium at high sampling rate (down 0.25 ms depending on the length of the array). Data are recorded by the WaveLab (Figure 8) that is a Windows based recorder that may be synchronized with the 428XL via the VE464 for joint surface 3D and VSP operations. It has full testing capabilities during deployment and acquisition thanks to the WaveControl software.

The SlimWave array (Figure 8) with up to 24 3C levels is for slim borehole applications, including tubing. Thanks to a pull-down tractor it may be used in horizontal well. They are more than 200 levels in operation, mainly used for micro-seismicity monitoring. The GeoWaves array (Figure 8) with up to 32 levels is designed

for VSP operations in open or cased hole with a deviation up to 60° and in hostile environment (up to 180°C & 22,000psi) like for deep offshore and shale gas. They are about 300 levels in operations, particularly in China. The MaxiWave (Figure 8) is capable of up to 100 3C levels with a 2000m antenna aperture at a 2ms sample rate. Such long array significantly improves seismic imaging and speeds up 3D VSP operations that do not require anymore several runs. For efficient operations with such high amount of level, it benefits from a unique bypass function in case of a satellite failure and from a safe spring loaded locking arm design allowing easing retrieval both in cased and open hole. They are more than 500 levels and 9 MaxiWave systems operating globally.

In summary, constant progress in geophysical equipment supports the continuous development of seismic exploration that becomes more sophisticated with high resolution, high density, wide azimuth and multi-component 3D surveys. All these technology progresses are aimed at improving seismic imaging and reservoir characterization, but this should be achieved by enhancing productivity to control cost and turnaround time. By insisting on the implementation of the latest technologies in the recording systems, seismic sources and sensors, SERCEL leads the market and the developments in the seismic equipment industry. As the world's largest manufacturer of seismic acquisition equipment, SERCEL supports worldwide the geophysical contractors which face more challenging surveys in remote and difficult areas.

Concerning the Chinese geophysical exploration companies, SERCEL pays much attention to their various requirements by designing new equipment more adapted to their needs and by continuously strengthening its customer support to provide domestic and international services “anywhere, anytime, everywhere” within 48h and with a continuously available hotline. The entire staff of SERCEL Beijing representative office sincerely hopes continuous progress and vigorous development for the geophysical exploration enterprises in China. **P+E**