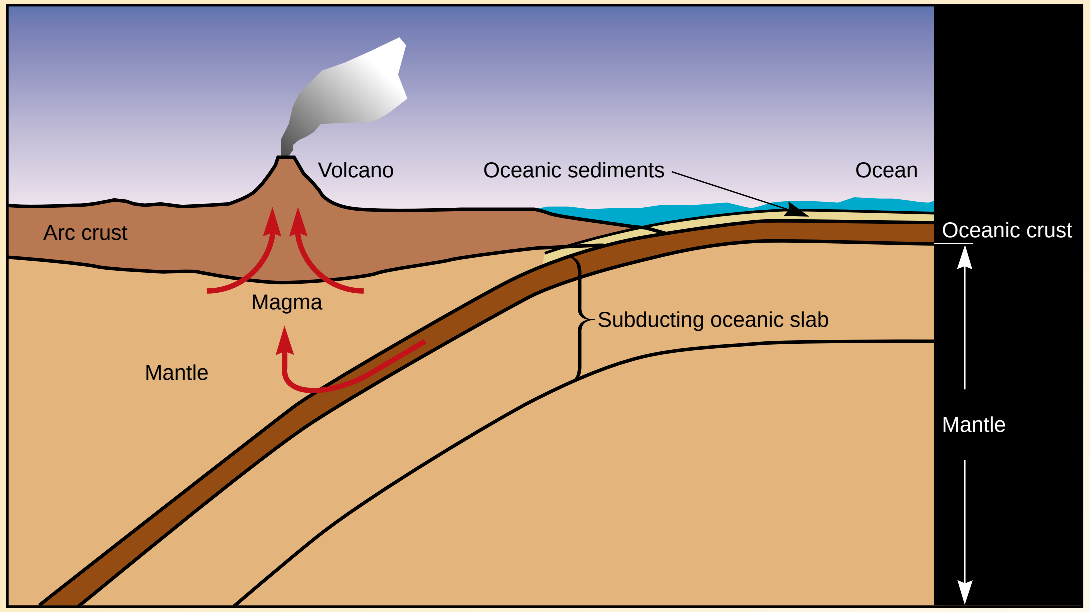

Figure 1. The oceanic slab subducts into the adjacent mantle. The oceanic slab includes the oceanic crust and part of the mantle, but whether it also includes oceanic sediments is a matter of some controversy among scientists.

Volcanoes

A Peek into Our Planet's Plumbing

MOST of us think of volcanoes as awesome or tranquil, depending on whether or not they are erupting. But we seldom consider that the magma belched up during an eruption represents a recycling of our Earth's most basic components—molten rock and gases that formerly lay deep within the mantle migrate up and finally are thrust skyward to become part of the crust and atmosphere. This activity not only forms new islands, mountain ranges, and large lava plains but also provides a brief glimpse into the dynamic processes that shape our Earth.

Volcanoes that lie along the edge of the Earth's great tectonic plates, like those in Japan, Indonesia, and the Aleutian Islands, constitute over 75% of all volcanoes that erupt above sea level. Known as island-arc volcanoes, they are the dramatic result of continuous interactions between the oceans, crust, mantle, and atmosphere.

Along deep oceanic trenches, the oceanic slab is thrust or subducted into the mantle bringing with it water from the ocean (see Figure 1). Water reduces the melting temperature of rock so that, as water is introduced to the mantle, the mantle melts. This melted material, known as magma, rises buoyantly until it erupts on the Earth's surface to form island-arc volcanoes. These eruptions are thought to be the major process by which mantle material is transferred to and becomes part of the Earth's crust. The gases from these eruptions also contribute to the formation of our atmosphere.

Understanding the chemical recycling at subduction zones has practical implications. For example, these volcanic eruptions affect global climate by releasing greenhouse gases into the atmosphere. The 1991 eruption of Mt. Pinatubo in the Philippines provided a stunning example of the effect that a volcano can have on global climate.

Annie Kersting, a geochemist with Livermore's Institute for Geophysics and Planetary Physics, recently completed a study of island-arc volcanoes on the Kamchatkan Peninsula, Russia, and on the island of Honshu, Japan, with scientists from Australia and Japan (see Figure 2). Her studies were designed to learn more about the processes that control the generation of new crust at island arcs. The consensus among geologists is that island-arc magmas are composed mostly of material from the mantle, with fluids from the subducting oceanic crust providing the mechanism for melting. But they are unsure to what extent the subducting oceanic sediments and/or oceanic crustal material mixes with the mantle and to what extent the thin arc crust immediately beneath the volcanoes contributes to the chemistry of the lavas that these volcanoes produce.

To determine the components of the magmas being studied, Kersting used long-lived isotopes of lead (Pb), strontium (Sr), and neodymium (Nd) as tracers. The so-called parental materials of lava—the mantle, oceanic crust, sediments, and arc crust—are isotopically distinct from one another, and the erupted lava will have the isotopic tracer or fingerprint of one or more of these parents.

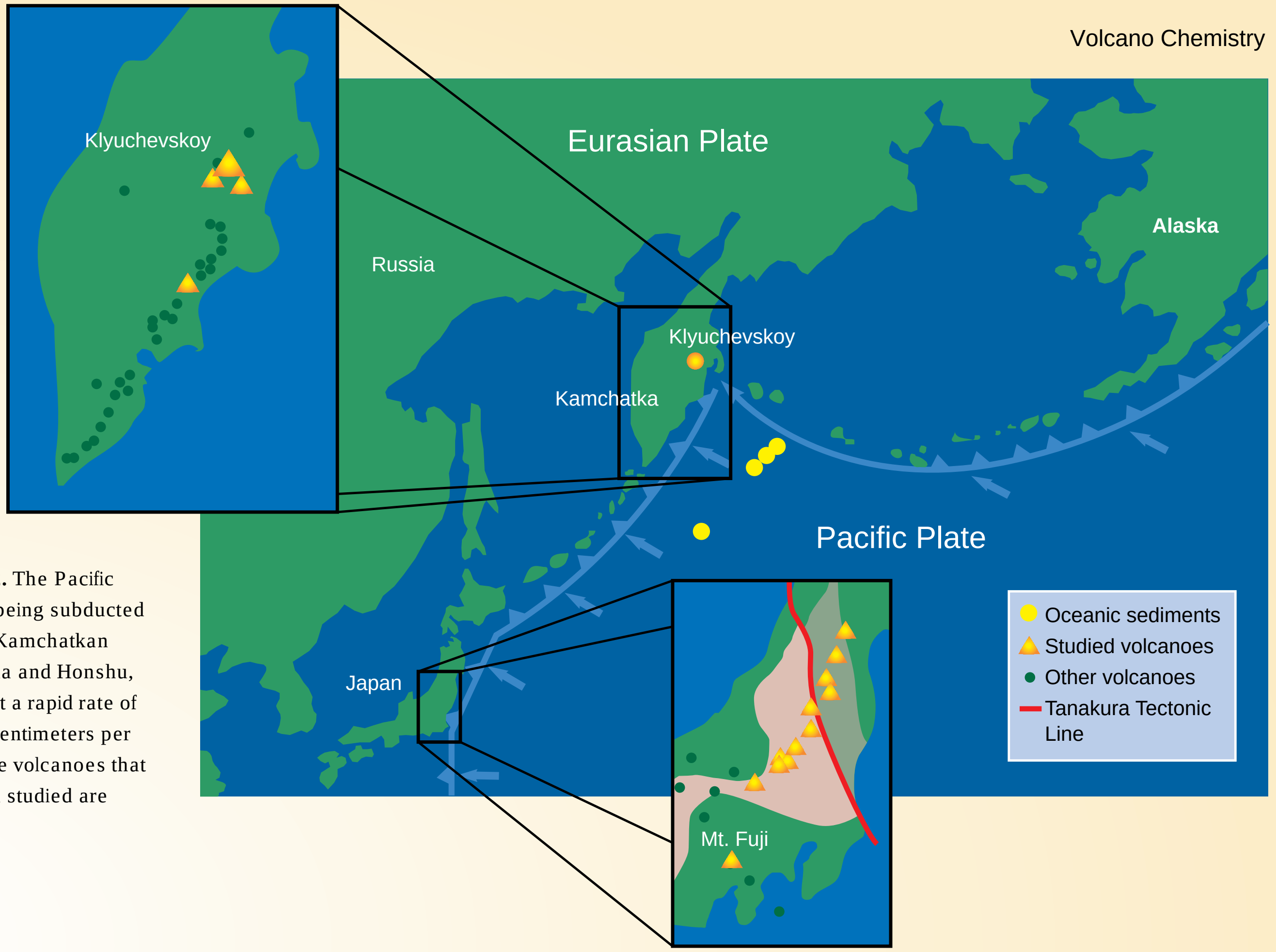

Figure 2. The Pacific Plate is being subducted into the Kamchatkan Peninsula and Honshu, Japan, at a rapid rate of 8 to 10 centimeters per year. The volcanoes that the team studied are shown.

Are Oceanic Sediments Involved?

Kersting's study of Klyuchevskoy volcano in Kamchatka, Russia, evaluated the influence of oceanic sediments in the generation of island-arc volcanoes. Klyuchevskoy is the most active island-arc volcano in the world (see Figure 3). A recent eruption blew volcanic material 15 to 18 kilometers above sea level and required the diversion of international airline traffic as a safety precaution.

The team first measured Pb, Sr, and Nd isotope ratios in basaltic rocks from Klyuchevskoy. They used Livermore's thermal ionization mass spectrometer, which can measure extremely low levels of these isotopes. The same ratios were measured in oceanic sediments from the North Pacific, parallel to the Kamchatkan arc. These sediments are the best analog for sediments that might have previously subducted with the oceanic slab beneath Kamchatka.

In all cases, the isotopic ratios of the lavas and Pacific sediments were different. Even a 1% sediment contribution to the lavas would be detectable, but there was none. Instead, the isotopic fingerprint was that of a purely mantle source. To verify these figures, the team also looked at three other Kamchatkan volcanoes and found similar results.[1]

"One area of controversy among geologists is whether oceanic sediments are carried down with the subducted oceanic slab and if so, whether they are melted and recycled into the arc crust via volcanism or scraped off and not subducted. This study indicates that sediments are not required in the production of island-arc volcanoes," says Kersting. In contrast, previous studies of other island arcs indicate that sediments are involved in magma generation. This work has shown that the involvement of sediment in the chemistry of arc magmas varies from arc to arc.

The Arc Crust's Contribution

In Japan, Kersting's team evaluated the effect that a relatively thin (30-kilometer) arc crust has on the magmas that pass through it. This research tested the widely accepted theory that only very thick (70-kilometer) arc crusts, such as those in the Andes, can influence the chemistry of lavas from the mantle.

Northeastern Honshu, Japan, is an excellent place to study this theory. The Tanakura Tectonic Line, a fault that penetrates the arc crust, cuts across an arc of active volcanoes

Figure 3. This NASA image of Klyuchevskoy was taken from the Space Shuttle at the time of a recent eruption that spewed material 15 to 18 kilometers into the atmosphere. The blue area is land, the white is snow-capped volcanoes, and the smoke in the upper left quadrant is coming from Klyuchevskoy, which is in the center of the photo.

so that the volcanoes form on two different arc crusts. The volcanoes are close together, which helps to minimize variations in other parameters that might influence the volcanoes' chemistry—the depth to the subducting oceanic slab, distance to the oceanic trench, thickness of the arc crust, and composition of the mantle and subducting oceanic crust and sediments. Thus, any differences in the isotopes from volcanoes on opposing sides of the fault must result from the compositional differences in the arc crusts through which the magmas rise.

After collecting rock samples, the team measured isotope ratios at Livermore and found significant differences in the Pb, Sr, and Nd ratios in the lavas from either side of the fault. According to Kersting, the different geochemical signatures between the volcanoes immediately north and south of the fault must result from chemical "contamination" by the arc crust as the magmas traverse it.

More recently analyzed data from Mt. Fuji, which lies on a third type of arc crust on Honshu, substantiates the team's findings, adding strength to the argument that the mixing of basalts from the mantle with the arc crust is an important process in island-arc volcanism. Even a thin arc crust is an active geochemical filter for magmas that move upward through it.[2]

Scientists are still a long way from fully understanding island-arc volcanoes and their effects on our planet and its atmosphere. But Kersting's work contributes to the body of knowledge that helps scientists define how the chemical exchange between the crusts, mantle, and atmosphere at subduction zones influences crustal growth and global climate dynamics.

—Katie Walter

Key Words: crustal growth, global climate, island-arc volcanoes.

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Optical Networks

The Wave of the Future

When our ancestors built fires on distant hilltops to signal to one another, they were using an early form of optical communication. This idea of using light to send information began to be developed scientifically in the 1800s, when British physicist John Tyndall demonstrated that he could (although just barely) direct light down a stream of water. He found that light could be guided by transparent materials if those materials were denser than air, and his insight, when followed by other scientific inquiry, culminated in fiber-optic technology.

Fiber-optic technology takes electric signals from our phones, computers, and televisions and transmits them more efficiently than other methods, making it possible to deal with the volume and variety of communications that constitute modern life. The information-carrying capacity of fiber optics is so great that it is far from fully exploited. It is being counted on to help solve problems such as the traffic bottleneck on the Internet.

The members of the National Transparent Optical Network (NTON) consortium are among those counting on fiber optics. The consortium (Figure 1) has received matching funds from the Department of Defense's Advanced Defense Research Projects Agency to test and demonstrate advanced optical components in a high-speed, all-optical communication network. The network is based on existing Sprint and Pacific Bell fiber-optic lines and has been operational since February 1996. Currently, it is being tested by users of large, emerging applications, and the consortium is actively soliciting the interest of other such test users.

The project's two components—next-generation optical technologies and the emerging applications used to test these technologies—are bound into one ambitious objective: to provide a transmission capability for a multitude of complex, advanced uses, at speeds of billions of bits per second, with complete security and reliability. NTON members are thinking beyond the needs of the Internet cruiser's ability to download large graphics files. They are envisioning users such as physicians of the future, who will be able to retrieve a host of complex medical records from various remote locations, perform remote telesurgery, or practice space telemedicine.

The Context for Livermore's Work

Lawrence Livermore leads the work on the prototype network, which is to integrate new, developing technologies into a logical and efficient working system. It is a fitting role not only because of the Laboratory's broad expertise in optics and large-scale computing but also because of its neutral perspective on work that ultimately must be commercialized.

Integrating the new technologies into a high-service-quality, high-speed network on which new high-capacity applications can be tested will promote the advanced applications and demonstrate the commercial feasibility of the new technologies. One important goal of NTON is to convince private-sector investors that the new optical components are worthy of commercialization and that the fiber infrastructure should be upgraded. But as Bill Lennon, Lawrence Livermore's project leader from the Advanced Telecommunications Program, points out, "While these innovations are necessary for technological advancement and

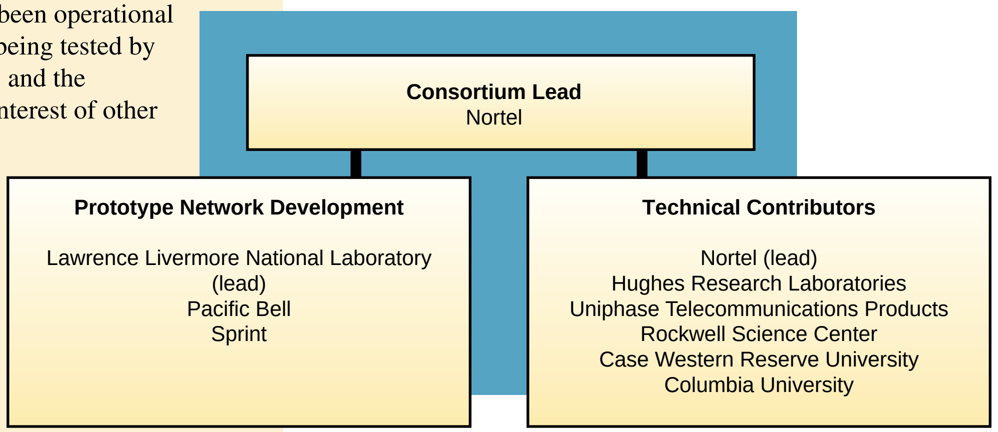
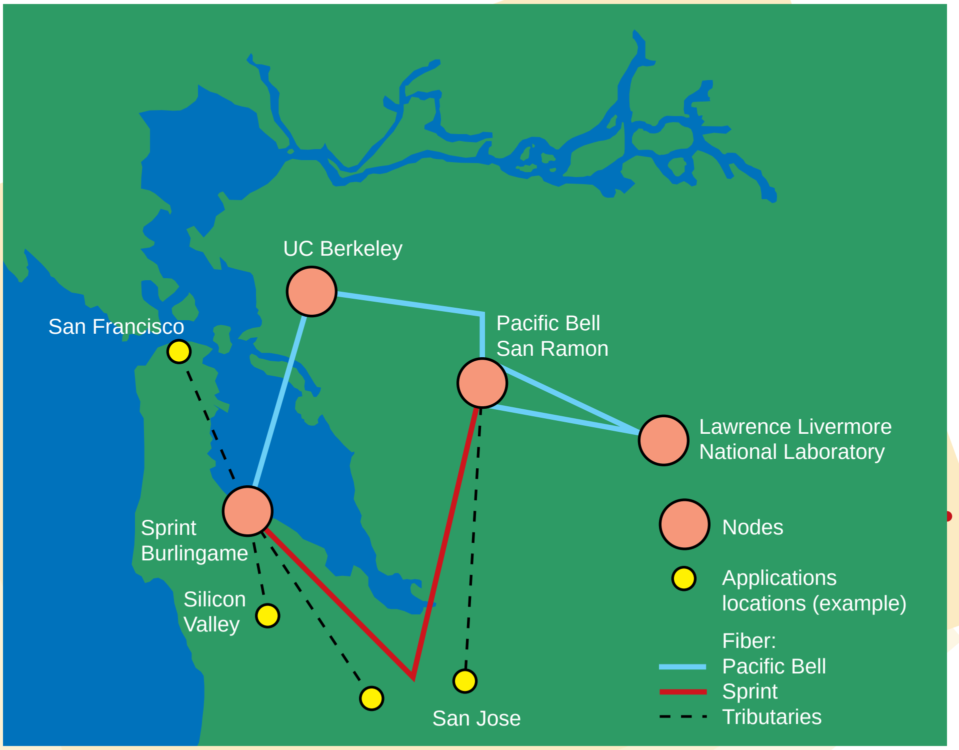


Figure 1. The National Transparent Optical Network is a consortium joining Lawrence Livermore with private-sector firms and institutions of higher education.

Figure 2. Currently, the National Transparent Optical Network consists of four backbone nodes connected by 600 kilometers of fiber that offer access to the network and route the streams of data passing through them. Tributary fibers will link them to other user sites where some 30 advanced applications are being developed and tested.



global competition, change is costly and investors are fiscally conservative. Investors must be totally assured of good returns on their money.”

Making More of Optical-Fiber Bandwidth

The all-optical network used in this demonstration resides in the San Francisco Bay Area and at present consists of four backbone nodes—at Pacific Bell in San Ramon, Sprint in Burlingame, the University of California at Berkeley, and Lawrence Livermore. The nodes, connected by approximately 600 kilometers of fiber, offer access to the network and route the streams of data that pass through. Tributary fibers will link them to other user sites, where currently some 30 advanced applications are being developed and tested (Figure 2).

The high speed and great capacity of the network are based on the inherently large bandwidth of optical fibers. Bandwidth is the expression of a medium’s communications capacity. Optical bandwidth offers, of course, the speed of light. But it also offers the whole rainbow of light frequencies. Having this capacity range can be likened to having a musical keyboard of many octaves, which can be used to play far more complex melodies than a keyboard of one octave.

NTON enlarges optical bandwidth capacity even more through a technique called wavelength division multiplexing (WDM), wherein each optical fiber is used to carry more than one wavelength. The various wavelengths do not interfere with each other, so each can be used as a different communication channel. (In the keyboard analogy, this characteristic would be tantamount to simultaneously playing a different song with each available octave.) The use of wavelength division multiplexing increases fiber capacity without the need to install more fiber cable.

The NTON fiber carries four wavelengths at present, but plans are to expand to eight ultimately. The capacity expansion that occurs with WDM requires new devices for regulating the resulting voluminous traffic. One of the new devices used in the network is being developed into a new product by Uniphase Telecommunications Products, a consortium member. It is an acousto-optic tunable filter (AOTF), whose function is to route the multiple wavelengths through the different regions of the network. Made of lithium niobate glass, the four-port filter selectively and simultaneously switches many wavelengths on their way to different destinations. Some other wavelengths are isolated by routing them to network-access equipment that “maps” their signals to a different wavelength. Because those signals are isolated by this blocking, their former wavelengths can be used elsewhere in the network. This wavelength “reuse” makes the system scalable, that is, able to indefinitely increase the volume of information being switched through (Figure 3).

A Flexible, Transparent Network

NTON is intended to be an open network; it must therefore be easily accessible to heterogeneous systems and formats (including future ones such as high-definition television), and users should work at their desktops without any awareness of its operations. In short, the network must be flexible and transparent.

These characteristics are achieved through the use of standards, the rules that enable systems to “talk” to each other. When different systems use different local formats, standards provide them with a common interchange language. Various standards are used in different layers of the network architecture to provide a hierarchy for signal transmission. The hierarchical process may be compared to having sheets of paper packaged into envelopes and delivered to an envelope handler who repacks them into boxes of envelopes, which are delivered to a box handler to turn into boxes of envelopes inside trucks, and so on through the delivery sequence until the packages arrive at their destination, where the reverse process yields the sheets of paper to the addressee.

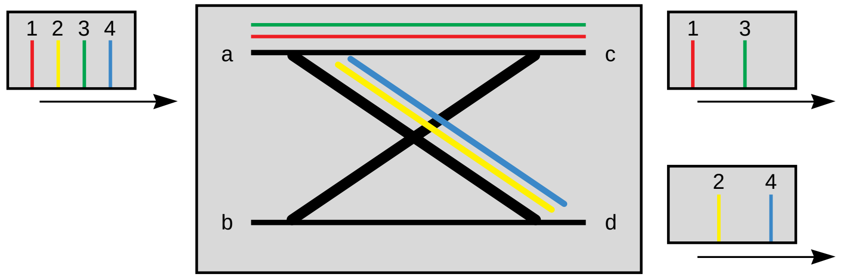


Figure 3. Uniphase Telecommunications, an NTON consortium participant, is developing an acousto-optic tunable filter (at right) whose function is illustrated above. Its ability to switch or block wavelengths enables their reuse, and thus the volume of information being switched through the system can increase indefinitely.

NTON uses two standards developed specifically for advanced networks. First, signals from various user formats such as video, data, and voice are fed into the network and converted into a standardized common format by means of the Asynchronous Transfer Mode (ATM) standard. ATM not only makes the signals insensitive to transmission format, it also assigns transmission space and priority according to the needs of the terminals, thereby making best use of network capacity and efficiency. After ATM, the signals must undergo another conversion to package them for optical-fiber transmission. This packaging is the function of the Synchronous Optical Network (SONET) standard.

SONET is particularly efficient. It keeps a signal and its management information together, and it synchronizes signals to a common clock to simplify handoff between the networks worldwide. These features make the signals easily and quickly extractable for distribution or routing. The SONET signals are the ones that are transmitted over one of the switchable wavelengths of the optical layer.

Demonstration Applications

The applications being tested on the network run the gamut from accessing digital libraries to accessing offshore geophysical data via satellite, from on-line collaborations on manufacturing design to remote processing or visualization of radiological records, angiogram analyses, motion rehabilitation therapies, and tomography images.

Recently, SRI’s Terra Vision, a three-dimensional terrain visualization program that runs on a high-performance graphics workstation, used the network to access multiple remote data servers; obtain real-time, high-quality terrain and battlefield data from these various locations; and transmit them as a computer visualization to another remote site. The visualization was a helicopter pilot’s roving-eye view of terrain in a military installation.

Another demonstration of the network involved an advanced simulation of magnetic fusion plasma turbulence, which was run in real time on a Cray supercomputer at Livermore and displayed on a high-performance graphics terminal at a conference booth in San Jose. The test illustrated that with high bandwidth, remote visualization of supercomputing simulations was possible.

More of these futuristic applications are on the way, and the work of NTON aims at making them happen sooner rather than later.

—Gloria Wilt

Key Words: acousto-optic tunable filter (AOTF), Asynchronous Transfer Mode (ATM), fiber optics, National Transparent Optical Network (NTON), remote visualization, standards, Synchronous Optical Network (SONET), wavelength division multiplexing (WDM).

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