Arizona Geology

Vol. 32, No. 4
WINTER 2002

Published by the Arizona Geological Survey

THE STATE AGENCY FOR GEOLOGIC INFORMATION

MISSION

To inform and advise the public about the geologic character of Arizona in order to foster understanding and prudent development of the State's land, water, mineral, and energy resources.

ACTIVITIES

PUBLIC INFORMATION

Inform the public by answering inquiries, preparing and selling maps and reports, maintaining a library, databases, and a website, giving talks, and leading fieldtrips.

GEOLOGIC MAPPING

Map and describe the origin and character of rock units and their weathering products.

HAZARDS AND LIMITATIONS

Investigate geologic hazards and limitations such as earthquakes, land subsidence, flooding, and rock solution that may affect the health and welfare of the public or impact land-and resource management.

ENERGY AND MINERAL RESOURCES

Describe the origin, distribution, and character of metallic, nonmetallic, and energy resources and identify areas that have potential for future discoveries.

OIL AND GAS CONSERVATION COMMISSION

Assist in carrying out the rules, orders, and policies established by the Commission, which regulates the drilling for and production of oil, gas, helium, carbon dioxide, and geothermal resources.

Development Devours Aggregate

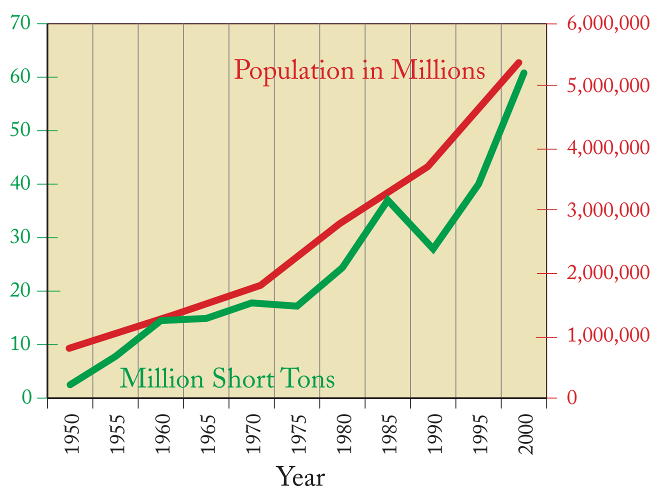
Larry D. Fellows, Director
Arizona Geological Survey

Population growth in Arizona since the end of World War II has required the use of large quantities of land, water, metallic and nonmetallic minerals, and energy resources for construction of new freeways, streets, shopping centers, businesses, offices, homes, apartments, and other structures. Increased traffic caused added wear on highways and streets, which had to be repaired or replaced sooner than expected. Major airports became inadequate and were expanded. As population growth and development continue, with no end in sight, even more natural resources will be consumed.

Limestone, gypsum, sand, gravel, clay, shale, and crushed stone are nonmetallic mineral resources used to make building materials such as cement, concrete blocks, bricks, mortar, wallboard, and plaster. Cement is a mixture of finely ground limestone, shale, gypsum, iron, and other components that have been heated to high temperature. Aggregate consists of sand, gravel, or crushed rock. Sand is made up of weathered rock fragments that range from 0.06 to 2 millimeters in diameter. Gravel particles are larger than sand; silt and clay-sized particles are smaller. Gravel particles are commonly produced by breaking or crushing larger particles. Concrete, a mixture of cement, aggregate, and water, is used to construct runways, highways, streets, and buildings. Asphalt, commonly used for pavement, is made from a refined petroleum product that is mixed with aggregate, which makes up about 95 percent of the weight of the asphalt.

Production of sand and gravel is directly related to population growth (Figure 1). Huge volumes of aggregate are required to construct highways, homes, businesses, and airports. For example, construction of just one mile of a four-lane interstate highway requires 85,000 tons of aggregate (Langer, W.H., and Glanzman, V.M., 1993). A typical 1,600 square foot house requires 100 tons of aggregate (Arizona State University, School of Business, 2002). Do you live in a home or work in an office that has a concrete slab or masonry walls? Do you travel on city streets, highways, or freeways or use airports? Do you use businesses or purchase things from stores or shopping malls? If so, you use construction aggregate.

Figure 1. Sand and gravel production is directly related to population growth. Population numbers are from U.S. Census compilations. Sand and gravel production figures are from U.S. Bureau of Mines Minerals Yearbooks (1950-1990) and U.S. Geological Survey Mineral Industry Surveys (2000).



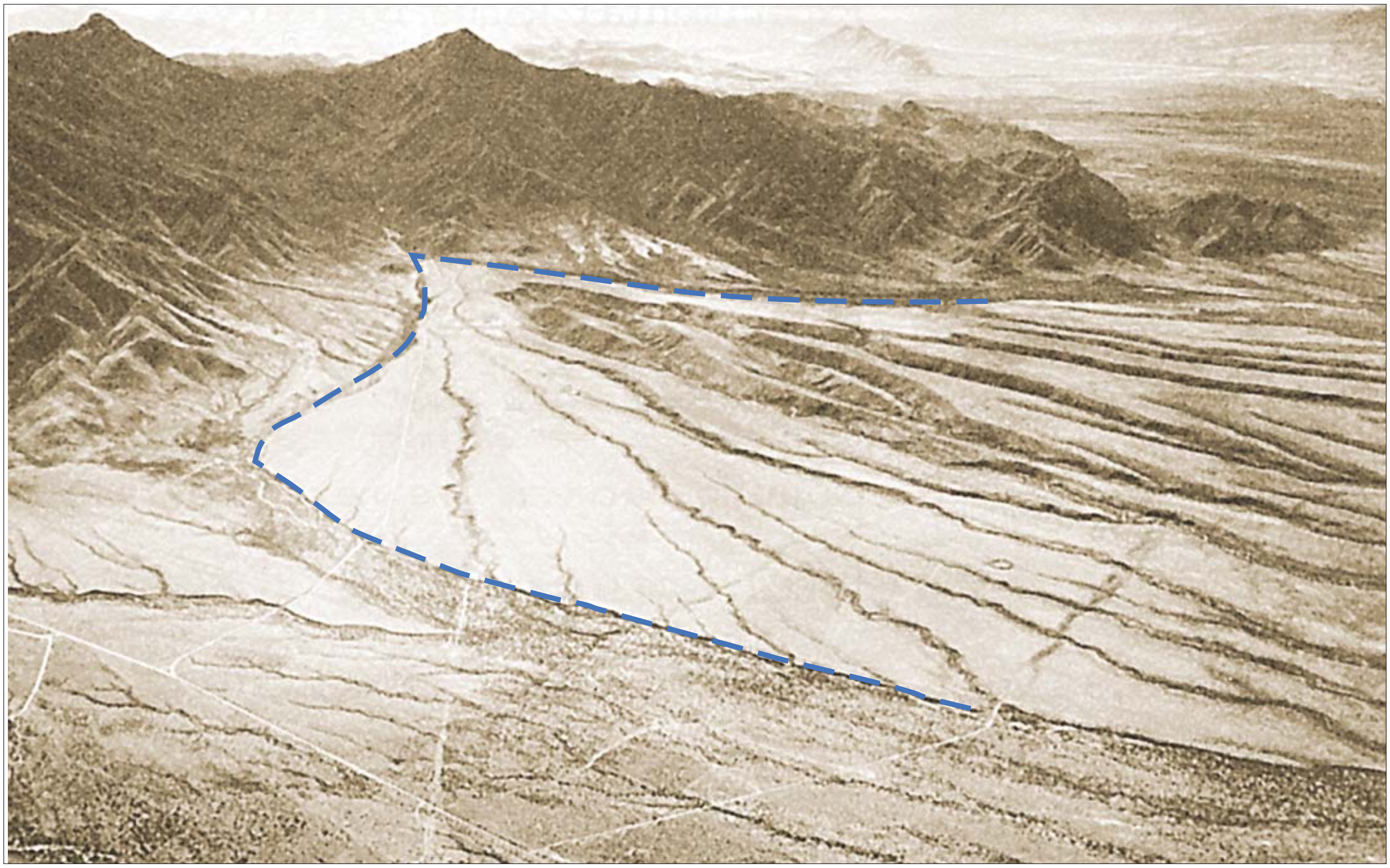


Figure 2. An alluvial fan (indicated by dashed line) was deposited where Madera Creek flows out of the Santa Rita Mountains south of Tucson. Photograph © Peter L. Kresan.

Role of geology. Geology determines the location and character of the sand and gravel deposits from which aggregate is obtained. Formation of sand and gravel begins when bedrock is broken into fragments by natural processes. Fragments range in size from boulders larger than an automobile to those too small to see without magnification. Some of the fragments tumble down slope in response to gravity as rock fall, landslides, or debris flows. Other fragments are transported and deposited by glaciers, wind, or running water. While being transported the rock fragments get rounded, sorted, and further reduced in size. Because geologic conditions are different in every area, sand and gravel deposits are not present everywhere. Even where they are present they are not equally suited for use as aggregate.

Natural processes by which hard rock is broken to bits are collectively referred to as *rock weathering processes*. They include freezing and thawing, wetting and drying, expansion and contraction, solution, and oxidation. The rate at which rock physically disintegrates or chemically decomposes is determined by factors such as temperature, rainfall, and the stability of the minerals in the rock. Freezing and thawing occur more often in areas with higher elevations than in the low desert. In the latter, wetting and drying, which cause expansion and contraction, may be a major rock-destruction process in some areas.

In general, the rate of chemical weathering, in which the composition of minerals in rock is changed, increases as the temperature and amount of water increase. Chemical weathering processes were probably more effective during periods of higher rainfall during the Pleistocene epoch than they are today. The Pleistocene, known informally as the Ice Age, started about 1.7 million years ago and ended when the last ice sheets melted about 8-10 thousand years ago.

During Pleistocene time, Earth's temperature warmed and cooled repeatedly in response to natural processes. In Canada, the northern Midwest, New England, and other parts of the world, cooling was sufficient to cause glaciers to form and advance several times. The weight of the glacial ice, which may have been thousands of feet thick, pulverized the underlying bedrock. Advancing glaciers pushed piles of rock fragments in front of them. When the temperature warmed, glaciers melted and meltwater streams transported some of the ground up rock fragments. In Arizona, glaciers and glacial streams transported only small quantities of sand and gravel, because glaciation occurred in only limited areas, including on San Francisco Mountain near Flagstaff and Mount Baldy near Greer.

Runoff from rain or melted snow transported and formed almost all of the sand and gravel deposits in Arizona. In many of the major streams and dry washes in southern Arizona water flows only a few days every year. Periodically during the Ice Age, however, the rainfall rate was substantially higher than it is today and many streams flowed permanently and flooded regularly. During those times rivers and streams widened, lengthened, and deepened their channels and transported sand, gravel, and other rock fragments much more effectively than today. Many of the sand and gravel deposits that are associated with drainage systems in Arizona were developed during past periods of increased rainfall and runoff.

Figure 3. Main channel and floodplain of the Gila River in Pinal County. Photograph was taken during the waning stage of the 1993 flood. Photo © Peter L. Kresan.

Streams are natural rock-tumbling systems. As rock fragments tumble downstream their sharp edges get worn down and the particles get broken into smaller pieces, just as they do in a rock tumbler. Fine particles, which require less energy to be transported, are moved farther downstream than coarse ones. In general, the farther downstream weathered rock fragments are transported, the rounder, smaller, and better sorted they get. The particles that are least durable wear out first. The mineral quartz, a common rock-forming mineral, is hard and durable. After lengthy transportation, quartz may be the only mineral that remains in the sand and silt size fraction. At any specific locality, however, sand and gravel deposits usually consist of a mixture of particles of different sizes, shapes, and compositions that directly reflect the composition of their bedrock sources farther upstream. The extent to which the fine silt and clay-sized particles have been naturally washed out of the mixture is extremely important.

Sand and gravel deposits. In the West, tributaries that flow from mountainous areas into the valleys commonly form *alluvial fans* (Figure 2) where their gradients decrease and the water is no longer able to move rock fragments. Sand and gravel in alluvial fan deposits, in general, has not been transported far and contains a high percentage of silt-and clay-sized particles. Sand and gravel in stream channels or on floodplains are the most easily accessible and suitable deposits for production of aggregate.

Rivers and streams change constantly. Many may have transported and deposited sand and gravel, at least intermittently, for tens of thousands of years. During that time their channels shifted across broad, flat valley floors. Younger deposits were laid down on top of those that were previously deposited. As a result, older sand and gravel deposits suitable for use as aggregate may be present beneath a valley floor on either side of the present river channel (Figure 3). Because these deposits are buried and may be deeper, they are more difficult to locate. Also, when streams deepen their channels the original floodplain deposits may remain as terraces along margins of the river. Terrace deposits may also be potential aggregate sources.

Transporting aggregate to construction sites is a primary factor in determining its cost. It is, therefore, most economical to obtain the aggregate from as close to where it is needed as possible. Taxpayers or the consumers ultimately pay for the added transportation cost. Concrete must be produced relatively close to where it is used because it begins to "set up" soon after its ingredients are mixed.

Sources of sand and gravel for use as aggregate are present, at least in small quantities, in all of Arizona's counties. Deposits of suitable quality and quantity to provide the aggregate needs of Phoenix and Tucson are present along the major rivers: the Salt, Gila, and Agua Fria in metropolitan Phoenix and the Santa Cruz and Pantano in Tucson. Large portions of the Colorado Plateau in northern Arizona are underlain by soft sedimentary rocks that weather into particles that do not make durable, acceptable aggregate. In those areas it is necessary to produce aggregate by crushing selected hard bedrock units.

Undesirables. Certain types of rock fragments are unacceptable for use in concrete. Chert, a siliceous substance that is common in some limestone, "pops out" after repeated freezing and thawing and, therefore, is an undesirable component. Siliceous volcanic rocks and other types of rocks are also undesirable in concrete and must be avoided. Stewart Mountain Dam, which creates Saguaro Lake on the Salt River east of Phoenix, is a good example. Concrete in the dam contains aggregate that was taken from the Salt River at the dam site. During construction in the late 1920s nobody knew that the gravel composed of highly siliceous volcanic rock would cause a problem. However, a chemical reaction took place in the gravel where it was in contact with the cement. That "alkali-aggregate reaction" caused the concrete to expand and deflected the top of the arched dam 6 inches upstream. The expansion, first noticed in 1943, stopped by the mid 1960s. The U.S. Bureau of Reclamation did remedial work in 1985 to rehabilitate and strengthen the arch. The potential for further reaction in the future is considered very unlikely.

Fine particles (those in the silt and clay fraction less than 0.075 mm in diameter) are also undesirables. Sand and gravel must be relatively free of the "fines" in order for the cementing agents (both asphaltic and Portland cement) to effectively bind all of the particles together. Few aggregate sources in Arizona can be mined, crushed, or sorted without being washed to remove the fines. In general, 3 percent by weight of fine particles is the maximum allowed in either asphaltic or Portland cement.

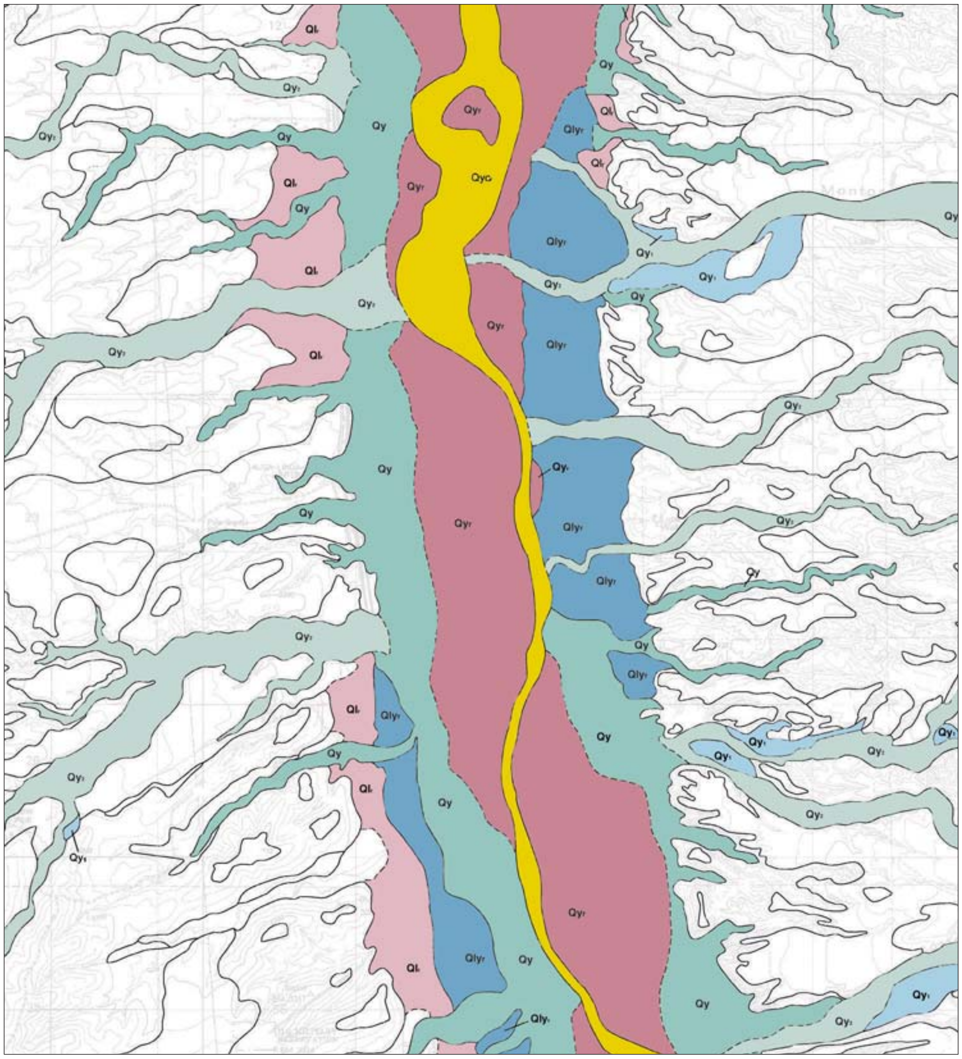


Figure 4. Portion of a surficial geologic map that shows sand-and gravel-rich units that were deposited by the Santa Cruz River and its tributaries. Modified from Youberg, Ann, and Helmick, W.R., 2001, *Surficial geology and geologic hazards of the Amado-Tubac area, Santa Cruz and Pima counties, Arizona*: Arizona Geological Survey Digital Geologic Map 13.

Geologic maps. Arizona Geological Survey geologists map the distribution of bedrock and surficial materials, including sand and gravel units. These maps, which show sediment that was deposited in modern stream channels, ancient river channels, and alluvial fans (Figure 4), may be used as tools to help identify areas with potential aggregate resources. Although the some of the deposits mapped contain a high percentage of sand and gravel, these deposits cannot be defined as aggregate resources until test drilling has been done to determine their characteristics. Drilling is necessary to determine the thickness of the deposit and to obtain samples. The samples are studied to determine particle size, shape, composition, degree of sorting, and other necessary characteristics. The thickness and character of a sand and gravel deposit are important factors in determining whether or not a deposit can be produced commercially.

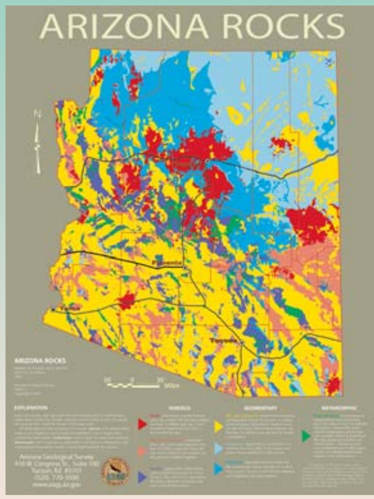
Conclusions. The location and character of sand and gravel deposits, from which aggregate resources are obtained, depend on two geologic factors: 1) the composition of the bedrock from which the sand and gravel were derived and 2) the extent to which the particles were shaped and sorted as they tumbled downstream from the source rock, including the extent to which the fine particles were washed out. The most easily accessible sources of high quality aggregate are in and along modern river channels and floodplains. Other suitable resources may be obtained from terrace deposits along modern river channels or from older channel or floodplain deposits that are buried beneath the present land surface. Because geologic conditions are different in every area, some areas have limited sources of aggregate, if any at all, and the quality of the aggregate that is available locally may be variable. High quality aggregate resources are not present everywhere. Because aggregate is essential for development, aggregate sources must be available.

SELECTED READINGS

Arizona State University, College of Business, 2002, *Impact of the rock products industry on the Arizona economy:* available for viewing or downloading at www.azrock-products.org

Langer, W.H., and Glanzman, V.M., 1993, *Natural aggregate: Building America's future:* U.S. Geological Survey Circular 1110.

ARIZONA ROCKS



This wall map shows shows seven predominant rock types in Arizona: three igneous rock units (granite, basalt, and mixed volcanic rocks), three sedimentary (limestone, sandstone, and silt, sand and gravel) units, and one metamorphic (schist and gneiss) unit. The full-color poster is 18 x 24 inches and on heavy stock.

Arizona Rocks: Richard, S.M., Spences, J.E., and Fellows, L.D., 2002, Arizona Geological Survey Poster 3. $6.95. (If ordered by mail, please add shipping and handling cost plus $1.00 for a map tube.

JUST RELEASED

Luke salt deposit: Rauzi, S.L., 2002, Arizona Geological Survey Map 36 (M 36), scale 1:62,500. $5.00 plus shipping and handling.

Naturally occurring radioactive materials (NORM) in Arizona: Spencer, J.E., 2002, Arizona Geological Survey Open-File Report 02-13 (OFR 02-13), 11 p. $4.00 plus shipping and handling.

Geologic map and report for the Buckeye 7.5' quadrangle, Maricopa County, Arizona: Skotnicki, S.J., 2002, Arizona Geological Survey Digital Geologic Map 15 (DGM 15), 1 CD ROM that includes a 15 p. text and 1:24,000 scale geologic map. $15.00 plus shipping and handling. (A paper copy of the text and map are available for $4.00 and $11.00, respectively, plus shipping and handling.)

Geologic map and report for the Avondale SW 7.5' quadrangle, Maricopa County, Arizona: Skotnicki, S.J., 2002, Arizona Geological Survey Digital Geologic Map 16 (DGM 16), 1 CD ROM that includes an 11 p. text and 1:24,000 scale geologic map. $15.00 plus shipping and handling. (A paper copy of the text and map are available for $4.00 and $11.00, respectively, plus shipping and handling.)

Digital graphics files for the Geologic Map of Arizona: A representation of Arizona Geological Survey Map 35: Richard, S.M., Reynolds, S.J., Spencer, J.E., and Pearthree, P.A., 2002, Arizona Geological Survey Digital Geologic Map 17 (DGM 17), 1 CD ROM that includes 1 Adobe Illustrator v5.0 file and 1 jpeg image file (200 dpi). $15.00 plus shipping and handling.

Geologic map of the Fortified Peak 7.5' quadrangle, southeastern Pinal County, Arizona: Orr, T.R., DeLong, S.B., Spencer, J.E., and Richard, S.M., 2002, Arizona Geological Survey Digital Map 18 (DGM 18), 1 CD ROM that includes a 1:24,000 scale geologic map. $15.00 plus shipping and handling. (A paper copy of the geologic map is available for $15.00 plus shipping and handling.)

Geologic map of the Durham Hills 7.5' quadrangle, Pinal County, Arizona: Richard, S.M., Youberg, Ann, Spencer, J.E., and Ferguson, C.A., 2002, Arizona Geological Survey Digital Geologic Map 19 (DGM 19), 1 CD ROM that includes a 1:24,000 scale geologic map. $15.00 plus shipping and handling. (A paper copy of the geologic map is available for $15.00 plus shipping and handling.)

NEW ARIZONA GEOLOGICAL SOCIETY PUBLICATION

Desert Heat–Volcanic Fire. A geologic history of the Tucson Mountains and southern Arizona: Kring, D.A., 2002, Arizona Geological Society Digest 21, 104 p. $16.00 plus shipping and handling. This book

PUBLICATION ORDERING INFORMATION

You may purchase publications at the AZGS office or by mail. Address mail orders to AZGS Publications, 416 W. Congress St., Suite 100, Tucson, AZ 85701. Orders are shipped by UPS, which requires a street address for delivery. All mail orders must be prepaid by a check or money order payable in U.S. dollars to the Arizona Geological Survey or by Master Card or VISA. Do not send cash. Add 7.6% sales tax to the publication cost for orders purchased or mailed in Arizona. Order by publication number and add these shipping and handling charges to your total order:

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