60°) is bisected by the greatest principal stress. This affords the guiding principle relating the orientation of common faults—normal, reverse, and transcurrent—to the associated stress fields.

Hydraulically induced fractures, whether by fluid pressure in wells or by the intrusion of igneous dikes, tend to follow surfaces parallel with the greatest and intermediate principal compressive stresses and perpendicular to the least stress. Therefore, the orientations of hydraulic fractures, or of igneous dikes and sills, are strongly influenced by the prevailing stress state in the ambient rocks. In particular, in tectonically relaxed regions characterized by normal faulting, the greatest principal stress is nearly vertical, and the intermediate and least principal stresses nearly horizontal, with the intermediate stress in the strike direction of the local normal faults. In such a region, the preferred orientation of hydraulic fractures is vertical and perpendicular to the least principal stress, and parallel with the strike of the local normal faults.

Hydraulic-fracture orientation may also be influenced by anisotropy or planar inhomogeneities in the rock such as bedding, schistose cleavage, or a system of parallel joints. If such a planar system does not depart too far from perpendicularity to the axis of least stress, hydraulic fractures may follow such a zone of weakness, across which the shear stress will not be zero. In this case, provided the rocks are also stressed tectonically, slippage along the fracture with possible resultant earthquakes is an expectable consequence of increasing the fluid pore pressure in the rock.

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Geometry of Sandstone Reservoir Bodies

Natural underground reservoirs capable of containing water, petroleum, and gases consist of sandstone, limestone, dolomite, and fractured rocks of various types. The character and distribution of sandstone and carbonate reservoirs are well known as a result of extensive research and exploration by the petroleum industry. Trends of certain sandstones are predictable because they are more regular and have been less affected than carbonates by postdepositional cementation and compaction.

The principal sandstone-generating environments are (1) fluvial environments such as alluvial fans, braided streams, and meandering streams, (2) distributary channel and delta-front environments of various types of deltas, (3) coastal barrier islands, tidal channels, and chenier plains, (4) desert and coastal eolian plains, and (5) deeper marine environments where the sands are distributed by both normal and density currents.

The alluvial-fan environment is characterized by flash floods and mud or debris flows which deposit the coarsest and most irregular sand bodies. Braided streams have numerous shallow channels separated by broad sand bars. Lateral channel migration results in the deposition of thin, lenticular sand bodies. Meandering streams migrate within belts 20 times their channel widths and deposit two very common types of sands. Bank caving and point-bar accretion processes result in lateral channel migration and the formation of sand bodies (point bars) within each meander loop. Natural cutoffs and channel diversions result in the abandonment of individual meanders and long channel segments respectively. Rapidly abandoned channels are filled with some sand but predominantly with fine-grained sediments (clay plugs), whereas gradually abandoned channels are filled mainly with sands and silts.

The most common sandstone reservoirs are of deltaic origin. They are laterally equivalent to fluvial sands and prodelta and marine clays and consist of two types: delta front or fringe sands and abandoned distributary channel sands. Fringe sands are sheetlike and their landward margins are abrupt (against organic clays of the deltaic plain). Seaward these sands grade into the finer prodelta and marine sediments. Distributary channel sandstones are narrow, with abrupt basal contacts and decrease in grain size upward. They cut into or completely through the fringe sands, and are also connected with the upstream fluvial sands of braided or meandering streams.

Some of the most porous and permeable sandstone reservoirs were deposited in the coastal interdeltaic realm of sedimentation. They consist of well-sorted beach and shoreface sands associated with barrier islands and tidal channels which occur between barriers. Barrier sand bodies are long and narrow, aligned parallel with the coastline, and characterized by a fine to coarse upward sedimentary sequence. They are flanked on the landward side by lagoonal clays and on the opposite side by marine clays. Tidal channel sand bodies have abrupt basal contacts, range in grain size from coarse to fine upward. Laterally they merge with barrier sands and grade into the finer sediments of tidal deltas and mudflats.

The most porous and permeable sandstone reservoirs are products of wind activity in coastal and desert regions. Wind-laid sands are typically very well sorted, highly crossbedded, and occur as extensive sheets.

Marine sandstones are those associated with normal marine processes of the continental shelf, slope, and deep, and those which are of density or turbidite current origin. An important type of normal marine sandstone is formed during marine transgressions. Although these sandstones are very thin, they are very distinctive and widespread, have sharp updip limits and grade seaward into marine shales. Two other types of shallow-marine sands (delta fringe and barrier shoreface) have previously been mentioned.

Many turbidites are associated with submarine canyons. These sands are transported from nearshore environments seaward through canyons and deposited on submarine fans in deep marine basins. Another type of turbidite forms as a result of slumping of deltaic facies occurring at shelf edges. Turbidite sandstones are usually associated with thick marine shales.

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Magnitude of Wastewater Treatment and Disposal Program Facing the Nation

More than 300,000 water-using industrial plants in the United States discharge 3-4 times as much oxygen-demanding wastes as all of the sewered population of the United States. Many wastes discharged by industries are toxic to aquatic life and sometimes indirectly to man. An infamous example of the latter is mercury. The volume of industrial wastewater discharge before treatment in 1964 exceeded 13 billion gal. Indications are that over half of this wastewater volume comes from 4 major industrial groups including paper, organic chemicals, petroleum refining, and steel.

Industrial pollution problems are created by oxygen-demanding wastewater constituents, organic and inorganic settleable solids, suspended solids, flotable mate-