Iydrology of Ielt-Water Channels in outhwestern Minnesota

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NTRIBUTIONS TO THE HYDROLOGY OF THE UNITED STATES

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HYDROLOGY OF MELT-WATER CHANNELS IN SOUTHWESTERN MINNESOTA

By GERALD L. THOMPSON

ABSTRACT

Melt-water channel deposits are among the most important aquifers in southwestern Minnesota, but permeable zones within the deposits are difficult to locate. Interpretation of the depositional history of proglacial channel deposits from aerial photographs and test-hole samples indicates the position of the permeable zones. Generally, the coarse-grained deposits are in headwater areas, near the confluence of two channels, in bends, or at the junction of sluiceways. Locally, these deposits yield as much as 1,000 gallons per minute to wells.

INTRODUCTION

This investigation, by the U.S. Geological Survey in cooperation with the Division of Waters, Minnesota Department of Conservation, and the Marshall Municipal Utilities, was made to determine the position of permeable zones in proglacial outwash deposits near Marshall in southwestern Minnesota and to relate these zones to their depositional environment. Sinuous melt-water channels lying within a wide outwash belt are the major source of ground water near Marshall. Similar outwash belts occur in other parts of southwestern Minnesota. Zones of high permeability in this outwash are the result of flow characteristics of proglacial streams. Extensive test drilling in a small area resulted in very detailed information on the stratigraphy from which the depositional history was reconstructed.

LOCATION OF AREA

The project area is in central Lyon County, Minn., at lat 44°26′ N.; long 95°48′ W. (fig. 1). It is about half a mile southwest of Marshall, the county's principal city, and about 135 air miles west-southwest of St. Paul.

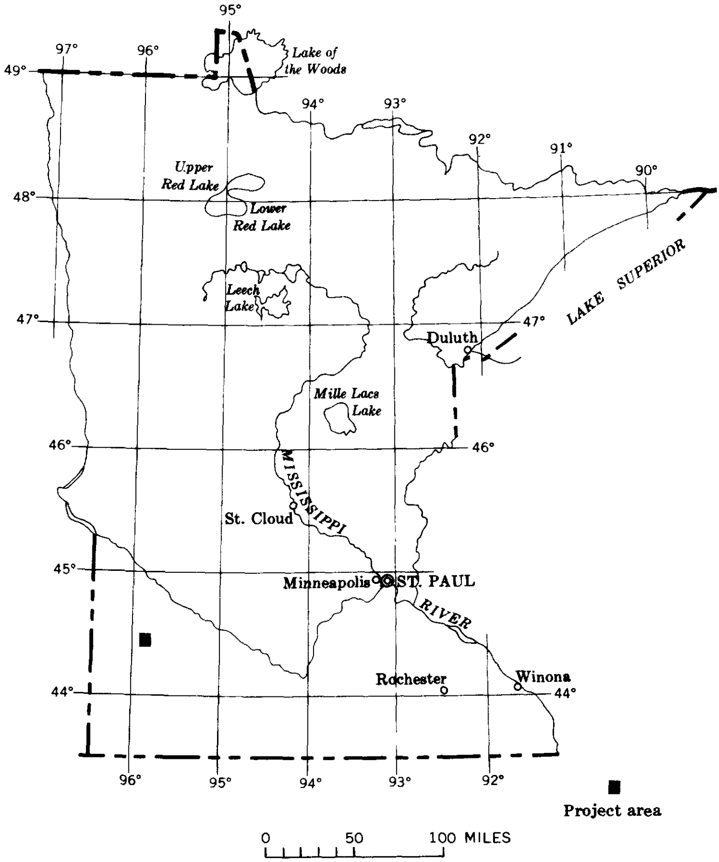

FIGURE 1.—Location of area discussed in this report.

TEST-HOLE NUMBERING SYSTEM

The system of numbering test holes and wells is based on the U.S. Bureau of Land Management's system of subdivision of the public lands. The first segment of a well or test-hole number indicates the township (T.) north of the base line; the second, the range (R.) west of the principal meridian; and the third, the section (sec.) in which the point is situated. The lowercase letters (a, b, c, and d) following the section number locate the well within the section. The first letter denotes the 160-acre tract; the second, the 40-acre tract; and the third, the 10-acre tract as shown on figure 2. The letters are assigned in a counterclockwise direction, beginning with (a) in the northeast quarter. Consecutive numbers are added to identify successive wells within a 10-acre tract. Figure 2 shows the method of numbering a well or test hole. In this example the well location is in the NE¼ of

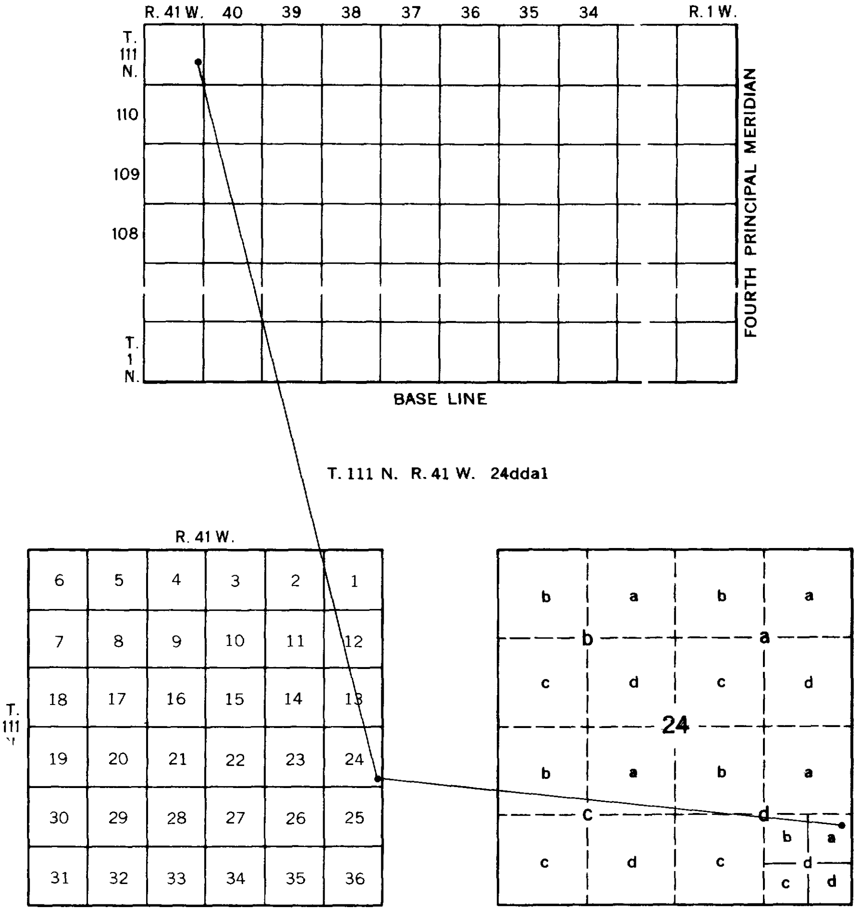

FIGURE 2.—Well-numbering system.

the SE¼ of the SE¼ of section 24 of T. 111 N., R. 41 W.; the well number is 111.41.24dda1 (T. 111 N., R. 41 W., sec. 24, dda1).

PREVIOUS INVESTIGATIONS

The geology and occurrence of ground water in Lyon County are described by Rodis (1961, 1963) and Schneider and Rodis (1961). Earlier geological reconnaissance of southwestern Minnesota was made by Hall, Meinzer, and Fuller (1911), by Leverett (1932), and by Thiel (1944). A current list of references is included in this report.

GEOLOGY

GEOLOGIC UNITS

The principal geologic units from oldest to youngest in the Marshall area are: basement granite of Precambrian age, dark-bluish-gray shale formation of Cretaceous age that contains some beds of permeable sandstone, glacial drift of Pleistocene age, and Recent alluvium. (See table 1.)

The project area is along the southwestern flank of the Marshall moraine (Mankato Stade of the Wisconsin Glaciation) in the area that Rodis (1961, fig. 1) mapped as surficial melt-water deposits. (See fig. 3.) Leverett (1932, p. 101) refers to the area as a "narrow plain that was probably utilized as a [glacial] border drainage course * * * but drainage features along it are rather vague."

Local glacial drift consists of stratified sediments in an outwash belt and clayey till associated with the Des Moines lobe. Because of the fine-grained texture and the scarcity of coarse material in the parent till, coarse permeable outwash is scarce.

EVOLUTION OF ICE-MARGINAL PROGLACIAL STREAMS AND SLUICEWAYS

Proglacial melt-water deposition occurs during deglaciation and during times when ice advance and ablation are in equilibrium. Deposition takes place in a *sluiceway* (a broad incised channel and the included belt of outwash) or *channel* (a small channel such as the separate courses of a braided melt-water stream).

As water melts from the ice front, it leaves with the maximum velocity and load permitted by gravity, gradient, and turbulence. Considerable debris and energy are available for downcutting in the sluiceway. Where the glacier retreats, the sluiceway gradually migrates headward, and the former gradient decreases with added distance from the head. As the stream's local capacity to transport load is reduced by the decreasing gradient, deposition of the coarse debris begins and downward erosion diminishes.

The continued aggradation of outwash reduces the gradient even further. Melt water spills beyond the confines of the channel, and new melt-water courses at lower levels are sought within the sluiceway. The resulting network of semiparallel courses yields a braided pattern of melt-water channels. In a very broad sluiceway, more than one braided melt-water stream can flow.

A retreating ice front exposes additional areas in which sluiceways form in successive positions parallel to the retreating front (Rodis, 1961, fig. 3).

Idealized melt-water channel deposition in an ice-marginal sluiceway during the constant retreat of an ice front is shown in figure 3. The vertical gradation in grain size from the lower zone of coarse sediment to the upper zone of fine sediment is typical (Lee and Powell, 1961, p. 17; Norris and White, 1961, fig. 17.1), and it is significant to the availability of ground water because the lower zone is more permeable and hence more productive than the overlying zone.

TABLE 1.—*The principal geologic units in the Marshall area and their water-bearing characteristics*

[gpm, gallons per minute]

System	Series	Geologic unit	Approximate thickness (feet)	Description	Water-bearing characteristics
Quaternary	Recent	Alluvium	0–20(?)	Clay, silt, sand, and gravel associated with Redwood River channel.	Because of small thickness and areal extent, water yield is generally inadequate for domestic wells.
	Pleistocene (Wisconsin Glaciation)	Des Moines lobe drift (Mankato)	110–130	Glaciofluvial deposits: interbedded clay, silt, and very fine sand to very coarse gravel containing some cobbles. Mostly fine sand and silt except for coarse-grained debris deposited by narrow proglacial streams flowing in the sluiceway.	Clay, silt, and fine sand are low in permeability but test wells in medium to very coarse sand mixed with fine to very coarse gravel yield up to 1,000 gpm from narrow channel deposits.
				Clayey till: silty and sandy, dark-bluish-gray, local layers very sandy and gravelly where older outwash is assimilated. Contains some lignite from underlying shale.	Clayey till is not considered water bearing.
Cretaceous	Upper Cretaceous	Shale	280±	Shale: commonly silty and sandy, soft to firm, dark-bluish-gray to medium-brownish-gray, contains pale-brown to medium-greenish-gray silt streaks and thin beds of fine-grained sandstone; lithologically indistinguishable from overlying clayey till.	Shale is not considered water bearing except for yields of 2 to 45 gpm from thin sandstone beds.
Precambrian		Granite	?	Granite: coarse-grained, pink, red, and gray, biotitic; creviced, weathered, and kaolinitc at top.	Impermeable except for yields of 1 to 7 gpm from weathered and creviced zone.

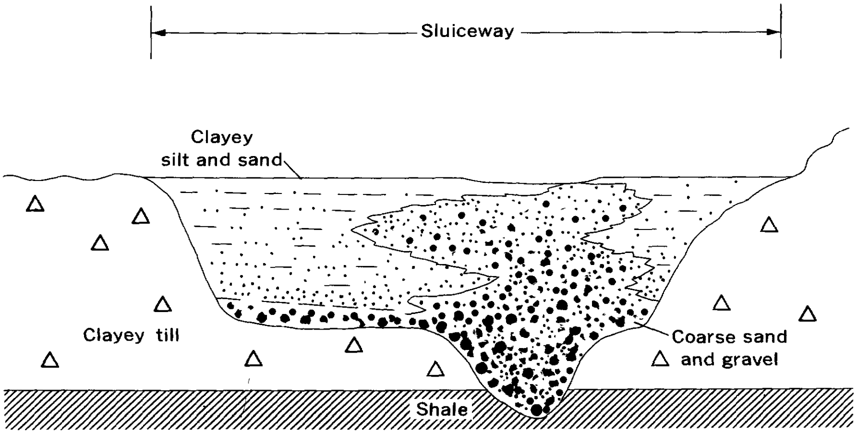

FIGURE 3.—Typical deposition in a sluiceway.

Most coarse-grained melt-water deposits are localized in the sluiceway in narrow sinuous braided channels where stream currents were rapid and turbulent. The fine sediments left the channels as suspended load in melt water, and thin deposits of coarse-grained sediments remain. In the large interchannel areas of the sluiceway, the deposits are dominantly fine sand and silt.

The present surface of the Marshall sluiceway shows no appreciable dissection in contrast to sluiceways in some other areas (Lemke, 1960, p. 84; Lee and Powell, 1961, p. 11) where recent intermittent streams are incising narrow channels. The Marshall sluiceway is a topographic low and is slightly below the altitude of the bounding till.

PHOTOGEOLOGY

The surficial traces of the Marshall sluiceway and channels are indistinct at most places in the field but can be seen on aerial photographs (fig. 4). In the project area, the sluiceway shows only one characterizing difference from the adjoining till areas: the sluiceway is flat, and the till is slightly hummocky (fig. 4).

The dendritic patterns of tone contrast on the photograph are shown as the axial traces of inferred channels on plate 2. The tone contrast reflects a textural difference in the underlying outwash (Ray, 1960, p. 33–36). In those channel areas where considerable coarse-grained sediment was initially deposited, general settling or compaction of the coarse-grained outwash is greater than in the fine-grained sediment of the interchannel areas (Flint, 1957, p. 141). Slight depressions form on the compacted coarse-grained sediment, and they serve as minor catchment basins for dark organic material and clay. The silt and clay layers of the interchannel areas hold considerable water, and

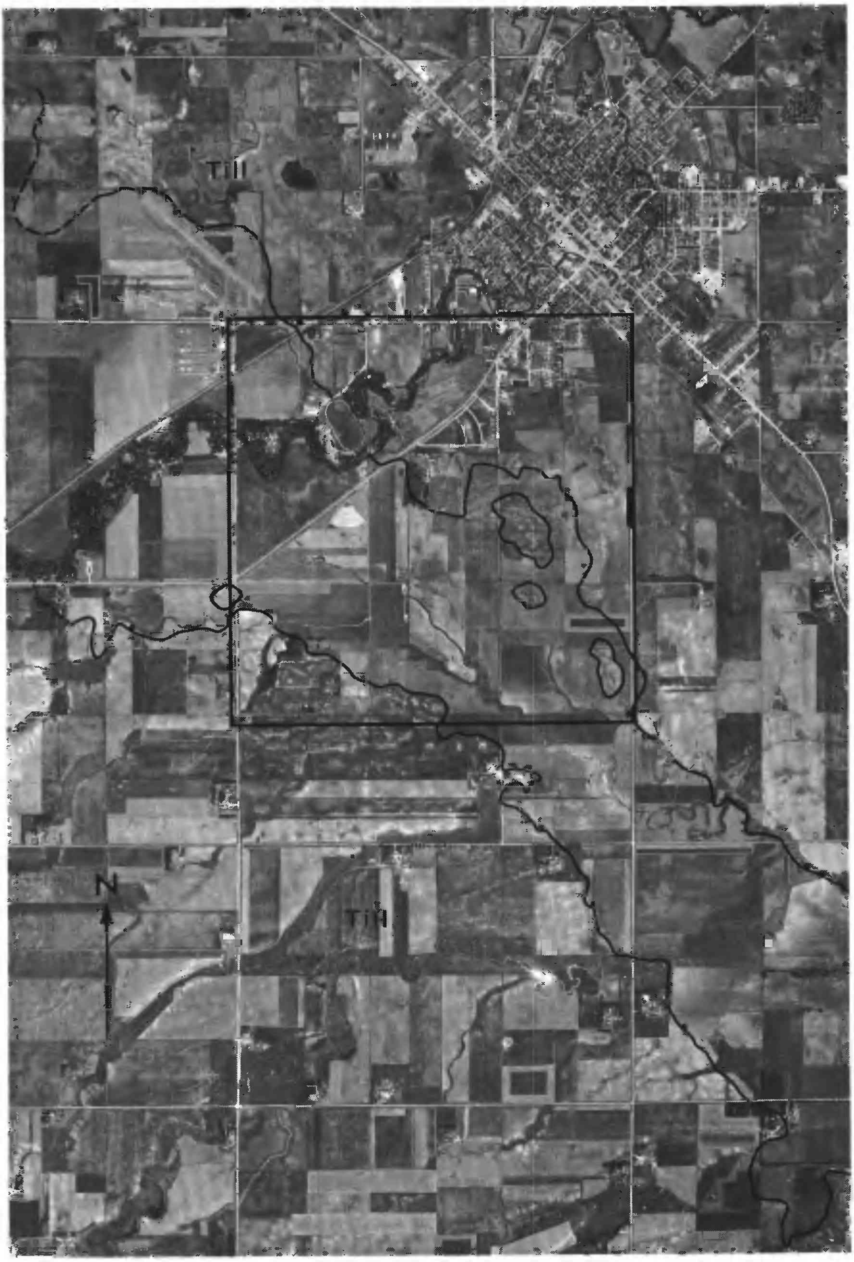

FIGURE 4.—High-level aerial photograph showing flat northwest-trending sluiceway near Marshall, Minn. Mottled surface in northeast and southwest is hummocky till deposited during Mankato Stade of Wisconsin Glaciation. Square outline encloses project area.

they do not readily change volume. Light-colored parallel zones commonly border the dark-colored pattern of the inferred channels. The light-colored zones are dry oxidized surface areas overlying permeable material, and the dark-colored zones are moist clay and organic humus that collect in the settled axial depressions.

INTERPRETATION OF TEST-HOLE DATA

The map of surficial geology (pl. 1) shows all wells and test holes in the project area for which logs of geologic sections are recorded. Geologic contacts between the surface outwash in the sluiceway and the bordering clayey till were determined by interpretation of aerial photographs. A few patches of till crop out in the sluiceway.

The melt-water deposits are grouped as fine-grained and coarse-grained outwash. Fine-grained outwash includes clay, silt, and very fine to medium sand. Coarse-grained outwash includes medium to very coarse sand, very fine to very coarse gravel, and some cobbles of unknown size. The fine-grained materials yield small quantities of water. The specific yield of the coarse-grained deposits is high, and these deposits can yield large quantities of water to wells.

The fence diagram (pl. 2) shows the surficial geology as interpreted along the lines of section indicated on plate 1. The approximate direction of view is N. 56° W. The coarse-grained detritus was deposited by proglacial streams in channels in the Marshall sluiceway.

The thickest known sections of saturated coarse-grained surficial outwash occur below the axial traces of channels as shown on the fence diagram (pl. 2) and on the circle diagram (pl. 3). Inferred axial traces were transferred from the aerial photograph to the base map before test holes were drilled. The mapped positions of these traces on plate 1 were then adjusted on the basis of test-hole samples. Some traces remained as originally mapped; the maximum shift was less than 25 feet. In some test holes (111.41.17bab7) outwash deposits are beneath thick deposits of till. These buried outwash deposits have no surficial expression.

Six distinctive features characterize the permeability in the surficial outwash of the Marshall sluiceway.

1. The deposits are neither as coarse nor as permeable in the upper half of the outwash as in the lower half. The lower deposits represent a time when the ice front stood nearest to the sluiceway.
2. The outwash in the interchannel areas is dominantly fine grained, but under the inferred axial traces the outwash is coarse grained and permeable. The inferred axial trace marks the position of maximum settling in the deposits overlying the till. However, the lateral shifting or migration of the aggrading stream during

deposition may not be indicated by this trace. (See pl. 2, test holes 11.41.8ccc3–6, 111.41.8cca4–7, and 111.41.17bab3, 4.)

3. Test holes near bends in the axial trace generally contain more coarse-grained permeable outwash than test holes intersecting a relatively straight segment of the trace (pl. 3, test holes south from 111.41.17aba1, and 111.41.17adb1–3). Stream velocity and turbulence are greatest on the outside of a stream's bend; hence, the proportion of coarse materials deposited is greater than in a straight-channel segment of the stream.
4. A distinctive feature of deposition in the Marshall sluiceway is channel bifurcation. Where the channel splits and rejoins, as in a braided channel, a broadthick zone of coarse-grained permeable outwash occurs as evidenced by the samples from the line of test holes extending northeastward from municipal well 111.41.17abb1 (pls. 2 and 3). The influences which favor the formation of coarse-grained deposits in bifurcated channels are the same as those for coarse-grained deposits in bends; however, continuous lateral migration of minor bends in the area of bifurcation enlarges the size of the affected area.
5. Surficial evidence near Marshall does not show the position of buried zones of older coarse-grained outwash. However, older outwash in the lower part of some test holes (pl. 2) underlies clayey till and younger outwash. The buried outwash is lithologically similar to the surficial outwash. Low-permeability till locally separates the surficial outwash from the buried outwash, but the outwash deposits may be a hydrologic unit if they are connected elsewhere.

   Existing data do not define the total distribution of the buried outwash, and no known differential settling associates with it. Schneider and Rodis (1961, fig. 4) describe a buried outwash that they believe is connected to the southwest margin of the surficial outwash. This buried outwash may be a continuation of that buried outwash penetrated in some of the test holes drilled during this investigation.
6. The axial traces trend parallel to the sluiceway near Marshall, where the outwash is thick and coarse and deposition was from high-velocity streams. At the northwestward extension of the sluiceway, near Minneota, the outwash is thin, deposition of coarse-grain outwash was in narrow meandering bands from low-velocity streams, and the traces trend across the sluiceway.

GROUND-WATER CONDITIONS

The water table is less than 15 feet below the land surface in the sluiceway area. Ground water moves northward from the study area to the Redwood River (pl. 1).

The principal water-bearing deposits are highly permeable glaciofluvial beds of coarse sand and gravel that occur in narrow channels bordered by very fine grained outwash. Some water also comes from thin sandstone beds of Cretaceous age (table 1).

A municipal test well (111.41.8cca9) was drilled near Marshall in September 1962. It is about 20 feet southeast of U.S.G.S. test hole 111.41.8cca5, and an observation hole (111.41.8cca10) is 15 feet east-northeast of 111.41.8cca9. The site was determined from test-hole data obtained during the investigation. The well is 12 inches in diameter and contains a gravel-packed 20-foot screen set between 65 and 85 feet. It was pumped at rates up to 1,000 gpm (gallons per minute) for 4.5 hours with drawdowns of 43.4 feet in the pumped well and 14.8 feet in the observation well. The calculated coefficient of transmissibility from the pumping test is more than 40,000 gallons per day per foot.

The characteristics of a channel deposit change abruptly in short distances vertically and horizontally (pls. 2 and 3). The abrupt reduction in permeability between coarse-grained and very fine grained outwash forms an aquifer boundary. Most ground water comes from the interconnected narrow channels and from lateral facies of coarse-grained outwash that extends from the channels. The bordering fine-grained outwash yields water slowly. The best location for a well is in the confluence of tributary channels (pl. 3).

Induced recharge from the Redwood River may be possible. Several outwash channels reach within a short distance of the Redwood River. Continued high pumping rates in wells in the project area will extend the cone of depression in the pumping area to the vicinity of the river and may locally reverse the northward movement of ground water between the river and the pumped wells.

CONCLUSIONS

Interpretation of aerial photographs is the best known method for locating large-yield wells in glacial deposits of southwestern Minnesota. Dendritic patterns on aerial photographs mark the axial trace of coarse-grained deposits by proglacial streams in the Marshall area and probably in other parts of Minnesota where sluiceways parallel the frontal side of end moraines. The topographic expression of the coarse-grained deposits is generally indistinct in the field, although locally the surface is depressed.

The thickest and most permeable outwash is in the sinuous channel deposits underlying a surficial axial trace, near bends, at the confluence of tributary channels, and where braided channel deposits occur. Most coarse-grained deposits are in channels that are parallel to the trend of the sluiceway. Commonly, the coarse-grained deposits are less than 100 feet wide. Wells in the channel deposits can yield more than 1,000 gpm.

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