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PROPOSED WATER SUPPLY INVESTIGATIONS
Sidamo Province
Ethiopia

A Report by

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PREFACE

For centuries, the rich grazing lands of southern Sidamo Province Ethiopia have been explored for water by herdsmen following a powerful incentive—thirst. Their results, - small ephemeral reservoirs of surface water and dug wells to shallow bodies of underground water, - have not been sufficient to stabilize their precarious and migratory existence. Their contribution to the development of Ethiopia is correspondingly hampered. This challenge to the steady economic development of Ethiopia is not new to todays frontiersmen - earth scientists, engineers, agriculturalists and businessmen. but their team work is required. Specialists in range management and veterinary controls following geologists and hydrologists in their search for permanent water supplies must attempt to improve herds of livestock so that businessmen can systematically market the byproduct. There are reasons to believe that these attempts will be successful, will parallel other developments in Ethiopia and will provide greater stability to the people of this frontier.

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INTRODUCTION

The following is a report by David A. Phoenix of the U.S. Geological Survey, assigned by USAID/Lagos to make an evaluation of a proposed ground water development program in Sidamo Province, Southern Ethiopia, as requested by USAID/Ethiopia. This program is a part of a long-range livestock marketing scheme proposed for support to the Imperial Ethiopian Government by the U.S. Agency for International Development. This evaluation is based upon a field reconnaissance of some 20,000 square miles of Sidamo Province during the period February 15 to 25, and made possible by the judicious use of light aircraft and 4-wheel drive vehicles. Attention was mainly directed to ways and means for improving water supplies along about 450 km of the major marketing and livestock migratory route connecting the towns of Moyale in the extreme south consecutively northward with Mega, Iavello, Alghe, and Dilla. Cattle routes and grazing areas subsidiary to the main route were also examined from the air. Data held by the Imperial Ministry of Water Resources, by the Geophysical Observatory, and the Imperial Ministry of Agriculture, Livestock Division, and discussions held with officials of these and other development and research institutions of the Imperial Ethiopian Government provided valuable guidance to this assessment. Particularly helpful was the experience in air reconnaissance methods provided by air pilot A. Temple, and the intimate and first-hand knowledge of the country and its livestock problems provided by Ato Gebrehiwet Zere, Deputy Director, Livestock Division, Imperial Ministry of Agriculture, and Mr. S. T. Logan, Acting Chief, Agriculture Division, USAID/Ethiopia. These men accompanied the writer during the 11-day reconnaissance investigation.

The development of water supplies for livestock in Southern Ethiopia has until very recently been left to practical and ingenious methods employed through centuries of practice by nomadic herdsmen. Within the limitations of their resources, every conceivable natural situation favorable to the accumulation of water has been employed. Old corral sites, pot holes in granitic rocks, shallow excavations, and rocky hill sides are all used to collect and temporarily store the infrequent rainfall. Certain types of vegetation which subsist on shallow ground water are also known to them and places in which it grows are invariably the sites of dug wells. In fact, many of these dug wells have been so long and persistently used that they are now nearing the limits of nomadic ingenuity as useful watering sites.

Succinctly, the herdsman is probably as knowledgeable and resourceful concerning his strategic sources of water, whether it be from ephemeral streams or shallow ground water reservoirs, as the most sophisticated hydrologist, geologist, or modern day livestock expert. Unfortunately, he is nearing the limit of even his most ingenious and persistent efforts of repair and maintenance due partly as a result of increase in livestock population and partly as a result of the heavy demands upon existing water supplies. Estimates, for Sidamo Province, place the livestock population at about 1½ million animals and reportedly it is not uncommon for several thousand to be watered at individual sites in a day. Two solutions to the water shortage problem appear evident and practial. The first will require a decrease in the numbers of dependent animals and here the efficient reduction in numbers, and this by steady and reliable marketing,

will strengthen the pastoral economy of these people. The second will require new and increased water supplies from hitherto inaccessible or untapped reserves and for which several sources are believed available.

It is concluded that the exploration for and development of water supplied in this remote and underdeveloped part of Southern Ethiopia is both desirable and justified, but that it is attendant to difficult living and working conditions and to a high risk of failure if not supported by well-directed engineering assistance and by special preliminary geologic, and hydrologic guidance. Partly, the risks can be eliminated by careful studies leading to the selection of appropriate new watering sites both surface and underground and the improvement of existing sites. These studies may also provide guidance to other exploitable resources and hence increased economic interest in the area. Accurate base maps and improved roads and communication will facilitate the compilation of the required hydrologic and geologic data and, thus, eliminate other risks. A large measure of engineering talent will be required in these phases of work. Above all, successful utilization of both the underground and surface water resources, and ultimately the livestock, will require a careful blending of traditional practices with improved but uncomplicated methods of water utilization and management.

If taken alone, the pitfalls to be encountered by even the best of intentions in range management and livestock improvements in a new and unknown country are many. Certainly without access roads and engineering guidance, even of the most expedient type, drilling operations and the continuing logistic requirements of supply and demand in servicing wells

and in constructing and maintaining stock ponds will become burdensome if not well-nigh impossible. Also, without geologic guidance necessary to the siting of wells, to the accurate description of cuttings and subsurface strata, and hence to proper well-drilling design and development, it is quite likely that an entire well-drilling program will become a repetitive succession of failures. As for stock pond construction, subtile differences in the thickness and physical properties of alluvium and in vegetative cover, and the parent differences in composition, permeability, and porosity of the underlying consolidated rocks control not only the sediment transported by streams but they also determine to a large degree the occurrence of runoff. Throughout very large parts of Sidamo Province stream runoff is a rare event and this is probably a direct function of a well adjusted balance between climate, topography, geology, and vegetation. In Sidamo Province these relations are unknown but it is quite conceivable that the mere construction of reservoirs will be discouragingly inadequate to satisfy requirements for permanent water throughout the long dry season. If the shrubs and trees of which the area is abundantly supplied are wholly or even partly eliminated, will this upset nature's delicate balance and create even greater problems? One might also ask such pertinent questions as "Where are the rocks favorable to water?" "Will the pumping practices imposed on ground water reservoirs exceed their safe yield?" "Are there areas where the temporary impoundment of water will effectively recharge the underground reservoirs?" "Will the yield from windmill wells be great enough to meet the minimum needs for domestic and stock use?" "Where are the springs?" "Can they be improved?" These and similar and how unanswerable questions can only be satisfactorily solved by systematic

areal studies of the relations between runoff, geology, vegetation, and climate.

At present, outstanding deterrents to all but the most basic and exploratory types of assistance include a serious lack of roads, communication, housing, schooling, medical, and supply facilities throughout the area. It is not within the scope of this report to propose specific support to strengthen these desirable and necessary aspects of the long-range marketing program. However, the writer is familiar with practical methods employed in opening new and remote country, and it is to these and to the special preliminary studies that attention is directed.

The bare manpower necessities for the successful completion of even the most exploratory of projects in this remote and largely roadless country will require a well organized and highly qualified team of both engineers, geologists, and bulldozer mechanics and operators and well drillers who are willing and capable of "roughing it" and "coping" under frontier working conditions. However, without the requisite technical equipment and without an environment suitable for effective work, the best qualified and experienced personnel can accomplish little. Therefore, it is recommended that the provision of adequate equipment and housing be recognized as prerequisite for effective operations of personnel assigned to the project, and that personnel not arrive until these essentials are available.

The following sections summarize observations concerning the areas of proposed activity and investigation according to the following outline.

Introduction

Previous investigation and available basic data

Physical features

- Location and extent
- Climate and vegetation
- Topography and drainage (hydrology)
- Geology

Ground water developments

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PREVIOUS INVESTIGATIONS AND AVAILABLE BASIC DATA

At present large parts of Ethiopia are remote from routes of travel and therefore little is known concerning natural resources in these areas, and this is particularly true for large parts of Southern Ethiopia. Published maps, the basic prerequisites to the assessment of these resources are adequate only for the most general of reconnaissance purposes. In Sidamo Province these include maps at a scale of 1/500,000 and 1/1,000,000. Rudimentary topography, altitudes of some major landmarks, and the location of stratigic towns, roads, trails and water holes are illustrated on the generally available 2-degree quadrangles, scale 1/500,000 compiled by the Geographical Section, British General Staff and published by the War Office, 1946. The adjoining 2-degree quadrangles Stephanie (N.B. 374), Neghelli (N.B. 375), Rodulf (N.A. 371) and Moyale (N.A. 372) covering in all 4-degrees of latitude and 4-degrees of longitude were used in the field to plot geological and hydrologic relations and the air routes of travel covered by this investigation. The broad physiographic relations of Southern Ethiopia are also shown on the U.S. Air Force 1/1,000,000 world aeronautical charts and their equivalent but later compilations by the British War Office, the Lake Margherita and Marsabit quadrangles. Plate I showing the availability of water supplies in a part of Sidamo Province, Southern Ethiopia has been prepared from adjoining parts of these two quadrangles.

To assist in all phases of resource investigations in Ethiopia and the U.S. Army Mapping Mission has since October, 1963 been systematically obtaining air photo coverage of the country at scales of 1/50,000 and 1/25,000. Overlapping air photos, scale 1/50,000, along eastwest flight lines are now available for most of Southern Ethiopia and of the project area.

The results of reconnaissance geologic studies of Southern Ethiopia are summarized by Mohr (1961) and are illustrated on the geologic map of Ethiopia, scale 1/2,000,000; the general rainfall and air movement patterns over Ethiopia are illustrated and described by Tato (1964); and the classifications of soils and native vegetation sufficient to provide initial guidance to the recovery and management of water supplies in Southern Ethiopia are described by Murphy (1959) and Von Breitenbach (1961). Other general information in part applicable to water supply problems in the area include a discussion of water laws in Moslem countries by Caponera (1954); and reports on general geology and hydrology of the Upper Nile Basin in Ethiopia prepared by the U.S. Bureau of Reclamation (1963).

PHYSICAL FEATURES

Location and Extent

Sidamo Province embraces about 30,000 square miles in Southern Ethiopia extending from mountains bordering the eastshores of Lake Stephanie (a broad playa) and Lake Ruspolt in the Rift Valley, eastward to the southerly flowing River Daua Parma, and from the high plateaus of Southern Ethiopia southward to planar country along the international boundary separating Kenya and Ethiopia. It is a broadly triangular area with its northern apex in the highlands and adjacent foothills, and its broad basal area some 200 miles to the south covering the lower plains.

The greater part of the area covered by this report lies in the plains country in the Southern part of Ethiopia. The area encompasses approximately 3 degrees of latitude, from 3°30' North latitude to 6°30' North latitude, and its broad base extends from 37°00 East longitude to 40°00 East longitude.

From Addis Ababa the areais accessable by air transport and by road. A well-graded dirt airstrip is located about 8 miles northeast of Mega, it is suitable for landings by light aircraft, and it is reached by about 3 hours flying time from Addis Ababa. The airstrip is about one-half hours drive from Mega and a good three to four hours drive from Iavello, a small town of about 2000 inhabitants. (See figure 1). To reach Mega by road from Addis Ababa is a tiresome journey requiring the better part of three days travel. The first 107 miles of this road as far south as Shashemenne is paved. From here southeto Dilla the road can be negotiated throughout the year but in many places it is steep, winding, and rough and requires considerable caution to negotiate safety. From Dilla south to Mega and beyond, the road is one long series of washouts, ruts and detours, and travel is reduced to the almost full-time second or low gear speeds of a well-equipped Jeep or Landrover.

Climate and Vegetation

The mean annual rainfall ranges from about 400 millimeters (16 inches) in the southern plains of Sidamo Province to 1200 millimeters (47 inches) in the mountains to the north. It is probably less than 600 mm (23 inches) throughout most of the southern plains. At Moiale on the Ethiopian boundary and at an altitude of about 12000 meters (4,000 feet) the mean annual rainfall for five years of record is 819.5 mm. (32.1 inches) but at Dilla in the mountains some 200 miles to the north and at an altitude of about 1600 meters (5300 feet) the mean annual rainfall for 6 years of record is 1407.2 mm (55.4 inches). In the highlands the rainfall is monsoonal with a distinct dry season extending through the period from late October-

to mid-March. In the highlands also, a period of intermittent rains "the small rains" introduces the heavy rainy season, which usually begins in May or June and ends in mid-October. In the southern plains, at lower altitudes, the period of "small rains" in March, April and May is followed by a distinct dry season until the rains again occur during October and November. In the southern plains there are between 80 and 100 days during the year in which rains occur, and most of these are of short duration. Clear sunny days prevail throughout most of the year and day-time temperatures frequently exceed 100°F; The nights, however, are invariably clear, crisp and cool. Generally speaking in the mountainous parts of Southern Ethiopia working conditions are ideal throughout the dry season. In the plains at lower altitude ideal working weather prevails through the period from March to October and it is uncomfortably hot only during the midday for the rest of the year.

The prevailing directions of wind movement in Southern Ethiopia during the period from June to early September is influenced by warm moist southeasterlies comming in from the Indian Ocean. After a short period of vacillation, wind directions then change abruptly and during the dry season extending from early October through May of the following year the prevailing direction of air movement is toward the southwest (Tato, 1964). The duration and rates of air movement are not known for the area but in general air movement is believed to cease throughout most of the night and is again resumed during the mid-morning hours. Undoubtedly the area receives occassional violent winds that accompany thunderstorms and these are probably of short duration. Wind vilocities are believed to be adequate to operate windmills during at least 8 hours every day.

The various plant ecologies and assemblages found in Southern Ethiopia are mapped and described by von Brietenbach (1961) sufficiently to provide the student with initial guidance to their identity and hence to their relationships to water supplies and range management. In the area of this report as well as elsewhere in Ethiopia the distribution and types of native vegetation are believed to be largely as a result of differences in soils and climate. These are in turn related to differences in physical and chemical properties of the underlying rocks and upon altitude. In the basalt highlands near Alghe and Dilla where the native vegetation has not been replaced by farm lands and coffee plantations, and locally in the mountainous areas surrounding Iavello ad Mega, there are various forest species of tall plants and trees intermingled with dense thickets of high shrubs. (See figure 2). Outstanding in these forests are species of Acacia, Jumiperus, Podocarpus, Porteria, Euphorbia and Ficus. At lower altitudes and throughout the foothills and lowland country of Southern Ethiopia where soils cover metamorphic and intrusive rocks, the forests give way to an arid to semi-arid type of woody vegetation consisting of 9 to 15 feet high, short-stemmed shrubs overshadowed in many places by umbrella-shaped trees up to 25 feet high - the savannah woodlands of Acacia and thornbush. (See figure 3). Almost everywhere these trees and shrubs are underlain by a carpet of short-stemmed perennial grasses intermingled with annual grasses and herbs. In the most arid areas, noteably in the lava plains west and northwest of Mega grasses are the only form of vegetation over many square miles of country. (See figure 4).

Other observations concerning plant, soil and water relatiohships were necessarily limited to impressions received during the flight and ground traverns. In the foothills east of Iavello and northward to Alghe where rainfall is believed to exceed 30 inches per year plant growth is so dense that lateral visibility is reduced to 50 feet or less. At lower altitudes visibility is much greater, giving way to extensive tree-studded parks and grasslands. Throughout these areas the axes of the valleys are lined by trees and shrubs and with interconnected meadows, but the evidence for stream flow through them is in most places limited to dry ill-conected depressions and to narrow and shallow grass - covered channels. Furthermore there is little evidence to indicate that cattle find the trees and shrubs a palatable forage. In other places certain forms of vegetation also seem to prefer the vicinities of spring and seepage areas. These include Ficus, Euphorbia, Acacia, Salix, Lobelia and Tamarindus. It is suggested that some of these may be phreatophytes - i.e., plants which send their roots to the permanent water-table and depend upon ground water for their nourishment. If this is so they should be studied more carefully for they may indicate the presence of hitherto untapped ground-water resources.

Topography and Drainage

The area of this report occupies parts of two physiographic provinces in Ethiopia. These are the Southern Highlands, a high plateau surface on which altitudes are between 8,000 to 10,000 feet above mean sea level and to the south of this, separated by a broad belt of foothills, the Lowlands, a broad planar country broken here and there by inselbergs,

isolated mountains and clusters of volcanic craters. Altitudes in the Lowlands are between 3,500 and 5,000 feet above mean sea level.

The Rift Valley and its associated fault block mountains, one of the most continuous structural features on the earths crust, borders the area to the west.and on the east the area is bounded by the southerward flowing River Daua Parma. On the south it is terminated in part by a steep escarpment along which altitudes drop abruptly over 2000 feet. This escarpment faces southward over vast lava plains in northern Kenya, and parallels the international boundary from the vicinity of Moiale westward for almost 80 miles before it. then swings arcuately northward and dies out midway between and somewhat west of a line connecting Mega and Iavello. Along it are fault scarps and clusters of deep explosion craters.

A southerly trending group of disconnected liner ridges, extende southward from the Southern Highlands near Alghe and merges with the north end of the escarpment. These ridges form a somewhat sinuous and poorly defined drainage divide that separates the lowland area into nearly equal east and west parts. East of this divide, drainage is toward the Daua Parma or, further south, and east of Mega, onto a broad planar surface covering almost 5000 square miles of the southern lowlands. West of this divide, from the vicinity of Alghe southward to the western slopes of mountains surrounding Iavello, drainage is westerly and onto the distant playa surface of Lake Stephanie. Further south and from the slopes of the escarpment, drainage is dissapated in a southerly direction onto a northward continuation of the Kenya lava plains in Ethiopia. It is along and adjacent to this drainage divide extending from the highlands near Alghe to the international boundary at Moile that water supplies are needed to strengthen the migratory

and marketing routes for livestock from southern Sidamo Province.

Geology

The geologic map of Ethiopia, scale 1/2,000,000 shows that basaltic rocks of Tertiary age underlie the highlands in the northern part of Sidamo Province whereas intrusive and metamorphic rocks of Precambrian age underlie most of the southern part of the Province. The metamorphic rocks include all gradational types from those clearly of sedimentary origin to schists and gneisses so thoroughly altered that their origin is obscure. In most places they are highly distrubed by isoclinal folding. Granite and granodionite are the most common intrusive rock and these rocks are massive and unbroken. Pegmatites are common in basement complex rocks west of Iavello and probably elsewhere as well. In the southwestern part of the area the Precambrian rocks are overlain extensively by crystalline basalts of the Trap Series of Tertiary age; in the south central part they are overlain by lacustrine deposits of Quaternary age. All the consolidated rocks are mantled by deposits of recent alluvium including the sands of stream channels, clays and clay-rich soils of the hillsides and the valleys and coarse deposits of poorly sorted sand and gravel along the base of steep escarpments.

The consolidated rocks are also exposed in the walls of explosion craters about 8 miles northeast of Mega and at other localities west and northwest of Mega. El Sod, about 10 miles northeast of Mega is about one mile in diameter and 1,000 feet deep. (See figure 5). The near-vertical walls of this crater are composed of metamorphic rocks of the Precambrian complex and its rim is supported by nearly horizontal beds

of basalt some 200 to 300 feet thick. Megado, about 22 miles southwest of Mega at the base of the escarpment appears from the air to be somewhat larger and deeper than El Sod. Its inner walls are believed to be composed of rocks of the Precambrian complex overlain by several hundred feet of basalt. G. Gori, a crater about 52 miles west of Mega and well within the lava fields has walls about 600 feet high and they are believed to be composed entirely of basalt. Tuffaceous and other fragmental detritus ejected from these explosive craters may well comprise most of the rocks shown as lacustrine deposits of Quaternary age on the geologic map of Ethiopia.

The most striking structural feature in the area is the escarpment paralleling the Ethiopian boundary and bordering the southern part of the area. The southern face of this escarpment is a complex zone of southward dipping normal faults along which total vertical movement is probably 2000 feet or more. In other parts of the lowlands area in southern Sidamo Province faulting is not obvious and is believed of little importance in controlling the movement of either underground or surface water.

GROUND WATER DEVELOPMENTS

In general, ground water occurs under conditions where recharge is available from precipatation or stream flow and where soils and rocks are sufficiently permeable to absorb this moisture and to transport it to the zone of saturation. However, much of the water which seeps underground is intercepted by the water requirements of plants and capillarity and is returned to the atmosphere by plant transpiration or by evaporation before it reaches permanent bodies of ground water. In southern Sidamo Province ground water is believed to occur in thetuffaceous lacustrine

sediments widely distributed east and southeast of Mega; in and along zones of fractured rock associated with the faults along the steep escarpment along the international boundary; in stream alluvium overlying the basaltic rocks of the lava plains west of Mega; in beds of fractured Precambrian quarzite; and locally in alluvium in places along the valley floors and stream ways which decend from the mountainous areas surrounding Mega, Iavello and Alghe. The rocks which probably do not contain ground water, or in which it maybe too deep or difficult to reach and hence of little significance, include the unbroken metamorphic and igneous rocks of Precambrian age and the basaltic rocks of the trap series of Tertiary age that underlie extensive parts of southern Sidamo Province in the lowlands. With few exceptions the location of water-bearing zones and the amount of ground water available to wells even in the most favorable areas cannot be predicted with any degree of certainty from observations made during this study.

Developments of ground water in the area are limited to two boreholes at Iavello, one borehole at Mega and to ingeneous dug wells found in a number of places throughout southern Sidamo Province. The boreholes at Mega and Iavello were completed in 1964 by the Imperial Ministry of Water Resources. They are all less than 400 feet deep, cased with 6-inch A.P.I. casing, and fitted with small motor driven pumps. Each borehole and its installations are protected by locked shelters from which discharge pipes extend to nearby elevated storage tanks and from thence to spring-faucets where water is drawn for livestock or domestic use. At the time of our visit the borehole at Mega was in operation but the boreholes at Iavello were not being used due to mechanical troubles with the pumps. All of

these boreholes are believed to draw water from zones of saturated alluvium and through slot-perferated casing. The development tests performed shortly after they were drilled indicate they have specific capacities (yield in gallons per minute per foot of drawdown) of about 2.5.

Dug wells, the most common source of underground water in the area are the result of centuries of use and development by nomadic tribesmen. (See figure 6). Most of these are in the broad plainar area east of Mega where ground water occurs in tuffaceous lacustrine sediments. However, one well against the side of a small ravine and about 30 miles west of Iavello is excavated some 60 feet deep along a sheer zone in metamorphic rock and other were found in alluvium along a dry sandy stream bed in the lava plain about 75 miles northwest of Mega. These wells are all great distances from the most reliable source of water - the river Daua Parma. (See figure 7).

The wells east of Mega invariably occur in clusters covering several acres. However not all wells in a cluster are useful. Some are in good repair and show evidence of recent use other are rubble-filled depressions long since abandoned. The wells in use are generally surrounded by brush barriers and entered through a small holding corral. From the corral, cattle are led down a narrow inclined trench to a watering stage some 20 to 25 feet below the general land surface. The well shaft, usually 6 or 8 feet in diameter and nearly vertical is separated from the watering stage by mud-walled troughs and a low barrier of cribbed rock. Depth to water in many of these wells is 60 to 80 feet below the subsurface entrance and 80 to 90 feet below the surrounding land surface. To provide access to the water each well shaft is equipped with a number of crude log platforms or "stages", depending upon its depth, that are connected by ladders of

precariously wedged tree limbs. When watering cattle herdsmen descend into the shaft in sufficient numbers so that water in leather buckets can be conveniently passed from hand to hand upwards to the watering stage; as a full bucket goes up an empty comes down. The process is as efficient and productive as the agility and energy of the individual can make it. Indoubtedly an occassional bucket of water or even footing is lost in this rather dangerous enterprise. The results however, are satisfactory. It is reported that some 20 to 30 gallons per minute are hoisted upwards in this fashion and that the work goes on sufficiently to water at least a thousand cattle per day at each well. (See figures 8 to 14 inclusive).

It seems inconceivable that these wells are the result of a single bold enterprise to obtain water. All of those examined by us occur in settings where, under normal conditions, one might expect water to have been at some time in the past, either at or very near the land surface. Those east of Mega are located along the axes of very broad, low-gradient valleys leading from the mountainous areas surrounding Mega. In many places these valleys give the appearance of having once been areas of grassland and playas underlain by shallow ground water. It is interesting also that amongst the various abandoned wells in each cluster there are those that give the appearance of having once been simply open shallow depressions whereas others lack the entrance way so typical of the present-day deep structures. The evidence is inconclusive but in effect it would appear as though the nomadic herdsmen are now and/have over a long period of time been mining water and gradually deepending the well-shafts in persuit of a diminishing ground water reservoir.

Other direct sources of ground water are the springs which occur in the mountainous areas and the small lakes in the floors of the extinct explosion craters. Three springs were visited during the investigation - two near Iavello and one about a mile south of Mega.

The spring near Mega discharges from a thick, fractured bed of quartzite into a boulder strewn and tree-lined ravine. The bed of quartzite dips gently southward from the hills surrounding Mega and it probably receives recharge from precipitation which falls in these mountains. At the upper most source, water discharges directly from the quartzite but the yield at this place is less than one gallon per minute. Downstream cattle are watered at open pools in alluvium and also, in one locality, from a 25-30 foot deep well. (See figures 13 and 14). Reportedly a thousand or more cattle are watered here each day and if so, the discharge from the quartzite must be at least 20 gallons per minute.

At Iavello one of the springs discharges into a small open reservoir dug in alluvium. The floor of this reservoir is 10 to 15 feet above the roadway in a nearby canyon and it seems likely that water could be fed by gravity from the reservoir to nearby watering sites. There is no observable discharge from the reservoir. The second spring at Iavello is on a south facing hillside at the head of a large canyon about one and one-half miles northeast of town. This spring discharges from a nearly horizontal bed of fractured quartzite into a well-constructed spring box. This spring was improved at the expense of considerable labor by Italian forces who once occupied Iavello but the entire installation including the spring box, discharge pipe, a 9-foot by 12-foot by 6-foot concrete cistern and two 40-foot long concrete watering troughs has been neglected since their

departure and are no longer serviceable. It yields a small supply of domestic water to nearly villagers and it is also used for watering livestock.

Water in the explosion craters is limited to shallow lakes and small springs in the floors of the craters. In most places these lakes are saline and they are used as a source of salt. The small seeps and springs around the periphery of the lakes may be less saline than water in the lakes but they are at best a meager source of water. In most places the water in the explosion craters is believed to be unfit for livestock or human consumption. These craters indicate that the regional water table in their vicinity is far below the land surface and the hundreds of feet of metamorphic rock exposed in their walls are devoid of ground water.

SURFACE WATER DEVELOPMENTS

The behavior and amounts of surface water run-off from any area depends in large measure upon the frequency and duration of precipitation, upon the absorbent properties of soils and rocks, the water requirements of vegetation, and the slope and drainage areas involved. The retention and storage of run-off in reservoirs and hence their usefulness as watering sites depends upon how well the site is selected to avoid those elements which consume or retard run off. Ideally each site should be selected by one intimately familiar with run off characteristics of the drainage basin above the site and with the water retention properties of the site selected for a reservoir.

The only perennial streams in the area are the river Dama Parma and a few unnamed streams along the southern scarpment. Supplies of surface water for livestock in most of southern Sidamo Province must therefore

come from run-off that originats only during the rainy season and that probably continous for only a short period of time.

Reservoirs have been constructed throughout southern Sidamo Province as watering sites for livestock. In most places they have been built and are maintained through hand labor by the nomadic tribesmen (figure 15) but a few of more recent origin (figures 16 and 17) have been constructed with earth moving equipment by the Imperial Ministry of Water Resources. The capacity of the hand constructed reservoirs is in most places considerably less than one acre foot of water; the larger reservoirs are built to hold approximately 50 acre feet. In general the small reservoirs are located on or below rocky hillsides where rates of run-off are high and where the underlying materials insure agains water losses by seepage such as the granitic rocks of the basement complex. (see figures 18 and 19). In some places old corrals have been selected for reservoir sites probably because at these places the movements of livestock have created a more or less inpermmable floor to prevent losses by seepage. In other places natural basins in crystalline rock are usedas watering sites. Most of these small reservoirs probably contain sufficient water to provide for only a few weeks.use during the dry season. At least 30 of them were seen during our inspection of the area and the greater number were located in foothills surrounding Mega and Iavello. The "small rains" had just commenced in this area and many also contained water and were being used by livestock.

Four large machine constructed reservoirs were located during the air reconnaissance of southern Sidamo Province. One is on the eastern foothills of the mountain surrounding Mega, another is in the extreme southeast part of the area and about 33 miles northeast of Moiale, a third is

on foothills about 38 miles southeast of Iavello and the fourth is about one mile down stream from the mountainous entrance leading to the valley occupied by Iavello. Each of these reservoirs are of the same design and of approximately the same size. They are all rectilinear excavations measuring approximately 450 feet by 450 feet by 12 feet deep, and each is borderd on the down stream and lateral sides by an earth embankment about 15 feet high. Reportedly these reservoirs had been completed some two or three years prior to our field inspection. Out of these four installations only one contained water (Figures 16 and 17) and the amount in storage was but a small fraction of the available reservoir capacity. The absence of water-marks along the base of the small ditch leading to the reservoir suggested that only small quantities of surface run-off had reached the reservoir since its construction. Livestock in the immediate vicinity numbered no more than a few dozen animals and the general lack of footprints in the reservoir indicate that it is not being heavily used by livestock.

CONCLUSIONS AND RECOMMENDATIONS

Conclusions and recommendations resulting from this investigation are summarized on Plate 1. This map illustrates areas favorable, semi-favorable and unfavorable to the development of water supplies in southern Sidamo Province. Two classifications are shown, one of which emphasises areas for the development of underground water and a second which emphasises areas for the development of surface water. The map provides a general assessment of large areas and with exception of a few sites for explanatory boreholes does not illustrate specific locations for new or improved installations. More detailed geologic and hydrologic guidance in the selection of specific sites is recommended.

The large areas classified as unfavorable to the development of water are those in which it will be difficult and costly to drill boreholes; they probably have insufficient rainfall and topography to meet requirements for all but the most ephemeral of stock ponds; and they are underlain by rocks in which the occurrence of ground water is difficult to assess. Rocks underlying these areas are basaltic lavas of the Trap Series of Tertiary age and metamorphic and igneous rocks of Precambrian age. No known springs or seeps discharge from these rocks except in the bottoms of the deep explosion craters and the discharge from these places is meager and in most places chemically unsuitable for livestock. In most places alluvium covering these rocks is thin and is not water-bearing.

The areas classified as semi-favorable to boreholes and stock ponds are those in which gpound water occurs in deposits of sand and gravel underlying the beds and flood plains of ephermerad streams. In these places reservoirs will receive surface water largely as the result of occassional flash floods. In many places efforts to recover water will compete with the transpiration requirements of vegetation including thorn bush and acacia, with fluctuating water tables, and with restricted ground water reservoirs. The construction of boreholes and reservoirs in these areas should not be difficult but sites should be selected to obtain the maximum thickness of saturated alluvium and to avoid the distructive influence of floods.

Areas classified as favorable to boreholes only are underlain by stratified deposits of volcanic ash and by deposits of permeable sand and gravel. Recharge to these deposits originates from precipitation falling largely in the mountainous areas and it reaches the stratified deposits by the infiltration of stream run off. Discharge of this water is by

evaporation and plant transpiration and by hand methods employed at wells to satisfy the requirements of livestock. In areas west of Iavello and northwest of Mega ground water moves laterally towards large playas where it is lost by evaporation or towards areas where it is consumed by non-beneficial vegetation. The interception of this water by boreholes is believed feasable in many places. In areas east of Mega ground water either moves very slowly in lateral directions or not at all. It is contained in broad shallow reservoirs formed by the filling of topographic depressions on a surface of Precambrian rock with deposits of volcanic ash. The thickness of these deposits is not known but their water-bearing properties may be related to the distribution of the explosion craters. Ground water in these sediments occurs in joints and fractures and in places it may also occur in stratified deposits of sand and silt. Discharge of this water locally from depths exceeding 80 feet, is from hand dug wells clustered within at least six widely separated well sites. Yield of the wells by hand methods is sufficient at times to satisfy the water required by several thousand cattle per day. The producing wells are surrounded by abandoned wells in various stages of development. It is suggested that the discharge from the ground water reservoir maybe exceeding the natural recharge and if this is the case then increased production from boreholes may jeopardize the usefulness of the existing water supply. It is recommended that two test boreholes in the vicinity of a cluster of dug wells be constructed for observations of the water table. No more than three or four test boreholes should be drilled in these aquifers until information is obtained concerning their safe yield.

The areas classified as semi-favorable to stock ponds only are those in which the evidence for run-off, i.e., dry stream beds, is negligible. These areas cover foothills where upland surfaces support extensive parks and the valley floors are lined by thickets of shrubs and trees. The underlying rocks are dense unfractured granitic and metamorphic types and the alluvium mantling them, largely clay and silty clay, is probably no where sufficiently thick nor permeable to provide reliable year-around supplies of ground water. The water supply to reservoirs will probably compete heavily with the water required by evaporation and vegetation (transpiration).

Areas classified as favorable to stock ponds only are in the foothills surrounding mountainous areas where rainfall and run-off are believed sufficient to support both perennial and intermittent reservoirs of surface water, and where the rocks are igneous and metamorphic types and hence generally unfavorable to the construction of productive boreholes. In some places the rocks crop out over large areas but generally they are covered by alluvial deposits of silty clay, silt, and fine-grained sand. The thickness of the alluvium ranges from a featheredge on hillsides to probably several tens of feet in the valley floors. Locally these deposits of alluvium may be sufficiently thick and permeable and water-bearing to yield water to dug wells and boreholes. Sandy stream beds traverse the valley floors in many places. Both the hillsides and valleys are covered by moderately dense to dense woodlands and therefore with the exception of areas in which the rocks are exposed the water supply to reservoirs will probably compete heavily with the water required by evaporation and vegetation (transpiration). The elimination of certain types

of non-beneficial vegetation from drainage basins will therefore probably be required before the amount of water obtained by reservoirs is sufficient to support year-around requirements of livestock. In some places the vegetation is particularly vigorous and these places may reflect areas favorable to the development of small perennial springs.

Areas classified as favorable to stock ponds and springs are mountainous regions where the rocks crop out over large areas and where rainfall and run off are believed sufficient to support both perennial and intermittent reservoirs of surface water. In these areas the rocks are also sufficiently fractured so that in many places they store underground water; where their structure is favorable, the give rise to springs. The likely high incidence of rainfall and the likely reoccurrence of thunderstorms in these areas may also give rise to occassional heavy run-off or flash floods. Reservoirs should be constructed with these catastrophic events in mind. The springs in these mountainous areas nearly everywhere occur in the headwaters of canyons floored by permeable deposits of sand and gravel and overgrown with water-loving vegetation. In these places the water now available to livestock is probably only a part of the total amount of water discharged from the rocks and methods can be employed to increase and to localize this water supply. This work should not be undertaken without geologic and engineering guidance sufficient to obtain data on the physical properties of the water-bearing rocks and their geologic structure and the design and cost of appropriate containing and distributing structures.

Areas of pre-existing water supplies are in the highlands north of Alghe and in areas peripheral to the River Daua Parma and its major tributories. The occurrence and distribution of water in these areas should be adequate both in quality and quantity to meet needs for livestock without special installations or attention. However, these areas should be carefully investigated to determine the distribution of springs and their mode of occurrance and rates of discharge, and to determine the distribution and quantities of surface water supplies.

ELEMENTS IN PROPOSED PROGRAM OF INVESTIGATION

Element	Needed Special Equipment	Purpose
Drilling of exploratory and test boreholes. (6-8)	Rotary rig (available in Ethiopia.)	Search geologically favorable areas for underground water.
Determine water-bearing properties of sediments penetrated by boreholes.	Electric logger. (available in Ethiopia.)	Accurate delineation of aquifers and confining layers and improved correlation of strata, plus selection of zones most suitable for development.
Continuing record of water-level fluctuations (to start as soon as possible)	Automatic water-level recorder (Stevens A-35)	Identification of factors affecting water-levels, such as use of water from nearby wells, and periodicity and amount of recharge.
Measurement of depth to water in wells.	Steel Tapes (100 foot, 300 foot & 100 meters)	Same as above.

Determination of conductivity of water and other chemical properties such as pH, total iron, nitrate, fluoride and alkalinity.	Conductivity meter and Hach field kit.	Determine variation in geochemistry of water geologically and in depth.
Measurement of water discharge	2-inch flowmeters	Determine amount of water required by livestock and hence efficiency of windmills as a source of supply.
Measurement of water temperatures	Thermometers 20° to 212° F 0° to 100° C	Determine source of water
Measurement of stream flow	Price pygmy current meter and wading rod.	Determine stage and/or discharge of surface water.
Geological and hydrologic mapping	Air photographs scale 1/50,000 overlapping plus controlled mozaics.	Determine geological and hydrological boundary properties of rocks and overburden, calculate drainage areas and run-off.
Geological mapping	Brunton compass	Determine inclination of strata; their structure and position in the subsurface.
Geological mapping	Hand lens and geologist hammer.	Determine mineralogic and physical properties of rocks and their differences.
Compilation of data working office.	"Stripped" 30 foot trailer with chairs & drafting stool and tables.	Keep field observation and other records up-to-date, prepare maps and reports.
Communication	2-way short-wave radio.	Requests for assistance, spare parts, etc., advise on progress.
Records	Filing cabinet with lock (in trailer)	Categorize data, preserve records and other valuables.

Compilation	Drafting table and accessories (in trailer)	Determine spatial relations of rocks, water-bearing zones.
do	Office desk (in trailer)	Describe geology, hydrology recommend drill sites, stockppond sites, plan spring improvements, etc.
Interpretive report.		Explain the basic geology and hydrology of the region; provide guidelines for development of stock ponds and springs and additional wells as an aid in planning long range optimum use of all water resources.

WORKING AND LIVING CONDITIONS

During the field season the geologic and hydrologic investigations team will logically be based at Iavello. The nearest USAID office is at Addis Ababa, capital of Ethiopia and 300 miles north of Iavello. Iavello has an African population of about 2,000 people and small group of "expatriate" missionaries probably numbering no more than 2 or 3 families. The town is the center for administration affairs for southern Sidamo Province and hence the governor and the heads of military and police affairs also reside here. Amharic is the universal language; English and Italian are spoken but not by sufficient numbers of people to avoid the necessity for an interpreter or better yet, learning to speak Amharic. Foreigners are treated with utmost kindness and courtesy and this makes up in large measure for the lack of modern facilities and conveniences that are expected as a matter of course by most Americans. Conveniences such as stores, movies, banks, barber shops and the like are not equivalent to American standards or else not available. Water must be hauled from the nearby spring and boiled and filtered, laundary is done by hand, and cooking and

lights are obtained via coleman or butane. All provisions must be well stocked before leaving Addis Ababa and in a manner befitting one who is going into the field. During our brief stay in Iavello and elsewhere we lived in tents, and employed the assistance of a cook and driver-mechanic, both of whom could speak some English. During the dry season of the year a bus reaches Iavello about once a week from towns in the north and trucks loaded with supplies arrive almost daily; during the wet season transport of any kind is quite unpredictable. Expatriate families with children do not live here but the adventuresome wife will find it a hospitable and interesting setting for occassional visits.

Working in the field will require a good deal of camping out, probably for periods of up to a week or ten day at a time, and for reasons of both saftey and companionship it will be necessary to team-up with an experienced Ethiopian geologist or hydrologist. This will also provide a fine opportunity for the exchange of ideas and field methods between American scientists and members of the Ethiopian government. Geologic mapping and reconnaissance hydrology will necessarily resort to photo interpretation and to a good deal of footwork accompanied and assisted at times by packboard, pack mules, burros or camels. All-weather roads are non-existent and bush roads are few and far between, however, with care much of the country can be travegsed by a stout vehicle of the power wagon variety. Field men should bring a light over-under .22-shotgun, .30 calibre rifle and an effective side arm for procuring camp meat and for defense purposes. Thorn bush fences surround all native villages and compounds as protection against night mauraders and either this or all-night fires will be required at most camp sites. The area abounds in many species of antelope, giraffe, ostrich, and zebra as well as jackals, hyena, and several species of cat

including lion and leopard. Much has been said concerning theft and other bandit activities of maurading nomadic Somalis into southern Ethiopia. Most of this activity has been going on east of the River Daua Parma and north of the Somali border. It has been serious, and in fact on more than one occassion has resulted in skirmishes between Somalies and units of the Ethiopian army and Isolated instances of theft and aggression have at times penetrated as far west as Mega and Iavello. This activity is unpredictable, and unfortunately, in recent years it has been directed against both foreigners and natives alike. Originally USAID proposed the livestock marketing scheme for the area in which most of the depredations were prevalent but by circumstances and discreation it was moved westward to the more hospitable region adjoining Kenya. Indications are that this area will remain quiet and that with guidance from the governor and police force at Iavello and at Mega field work can be undertaken without serious consequences, particularly if work is first emphasized in the northern part of the area.

As discussed earlier these "opening" investigation[5] will require a good measure of frontier living under rugged conditions. Notwithstanding this, the technical aspects of the work appear to be extraordinarily interesting and challenging--- as do the non-technical aspects.

Ethiopia is a posting for which there is considerable competition amongst American personnel assigned overseas. All USAID families attached to the above development phases of the marketing program will maintain permanent headquarters in the capital city of Addis Ababa; they will join a close-knit American community that throughout the years has maintained a good deal of espirit de corps amongst its members. This is reflected in the excellent Post Report (1965) prepared for Addis Ababa.

PROJECT REQUIREMENTS

Personnel

The overall requirements in personnel for the opening of remote country both at home and abroad have been reiterated so frequently that they have become almost a part of the educational curricula for U.S. geologists, engineers, and hydrologists alike. Above all individuals selected for this assignment must exercise good judgement, have a healthy constitution, the desire to work eight days a week and the ability to "cope" in a part of Ethiopia for which communications and supplies are practically non-existent.

The reconnaissance investigation carried out in the area indicates that the chief handicaps to effective work will be great distances, a dirth of roads and an all to prevelant lack of communication, supply and repair facilities. Ato Gebrehiwet Zere who accompanied us on our trip is a good exampe of the type who should be recruited for this job. Although not a geologist he has the right attributes for being a good one. He is young (28) and eager to learn. He has entered the area with confidence, travelled alone via all means of conveyance, purchased cattle from nomadic tribesmen and in general most resourcefully set the stage for the livestock marketing program from this remote area.

Recommendations as to technical personnel are as follows:

Chief of Party: Mature hydrologist with sufficient training in qualitative and quantitative methods so that he can go out-way out on his own and do a good job; perferably over 40 and probably in a present grade of GS 13. He should have considerable experience in dealing with related geologic and hydrologic (including underground water) projects.

Field Hydrologist and Geologist:

These two men should be of equal grade probably GS 11 or 12 preferably unmarried, or if married accustomed to periods of separation from home and family, and with experience in quantitative and qualitative field methods employed in geology and hydrology. There are opportunities to develope excellent material for masters or doctors theses on the project. It is expected that the Imperial Government of Ethiopia will assign at least one geologist of the calibre of Ato Gabrehiwet to work with the technical staff and be based in the same field station. This would provide excellent opportunities for cultural exchange, one side contributing U.S. techniques and methods, the other a knowledge of the local conditions and problems. There is also a prospect that the project staff will include an Ethiopian hydrologist. Such addition to the staff would be welcomed, in order to develope competent technicains for carrying on when the project is completed.

Other major questions outside the field of hydrology but related to it are the social and economic effects of water supply developments; a subject of particular interest to the Imperial Ministry of Agriculture. It is realized that such studies will require visits to all sources of water supply and must depend in part upon data that are the concern of the geologist and hydrologist. No specific proposal has been made, but someone specializing in this field may be assigned to work closely with project staff.

Housing:

At present there is no suitable space in Iavello either for office or domicile. Realizing that the project cannot commence until such space become available it is recommended that USAID exert all pressures to provide

such space by a target date of January 1967. Requirements in the field will include three 32-foot house trailers, one of which can be fitted out with drafting facilities under local supervision, to serve as an office. Ancillary equipment should also include a small 10 HP motor driven skid-mounted generator (2,000 watt capacity), washing machine, hot water heater, an outdoor prefab type shower and two-wheel trailer mounted with a water tank of about 200 gallons capacity. Camp construction crews should bear in mind that trailers should be grouped at a site that will provide drainage, sufficient head for gravity feed to the plumbing system and a minimum of radio interference. Provisions should also be made for servents' quarters. All vehicles assigned to the project should be equipped with sturdy ball and socket trailer hitch. .

Communication with Addis Ababa must be effecient. It is recommended that short-wave radio receiver and transmitter in addition to and compatable with equipment already ordered for use by the livestock marketing program be obt obtained for the work. A mobile unit is not required.

Two power systems will be required, one electric for lights, radio and all electric-driven motors and a second propane, for running a hot water heater, stoves, and a compact deep freeze.

Equipment:

Following is a tentative list of equipment that will be needed. The "approximate costs" include many guesses, without benefit of catalogs, and may be highly inaccurate.

	Items from U.S. Manufacturer	Gussed Cost $
2	Water-level recorders, continuous, type A-35 Stevens	1,000
2	Water-meters, Sparling type 2-inch	400

1	Conductivity meter battery operated	300
2	Hach chemical kits for nitrate, iron, pH. Alkalinity, etc.	100
1	Leroy drafting set	50
1	Proportional divider, 12-inch	25
1set	Ships curves, triangles, drafting pens and pencils	20
1	Planimeter, K & E type	70
1	Drafting or drawing set	50
1set	Air photos, contact prints *	2,000
1set	Print laydowns, 1/125,000*	-
1	Generator (2,000 watt capacity.)	400
1	10 HP motor unit in combination with above	200
1	Wagoneer Jeep Station Wagon	2,500
2	Dodge power wogons, open bed, canvas cover, or equivalent	6,000
1	Two-wheel trailer with springs and 200 gal. capacity tank	800
3	House trailers 2-wheel 32 foot, gas range gas hot water heater and small refregerator in two; one bare of installations to be equipped with office furniture.	- 6,000
1	Small centrifugal pump and gasoline drive unit	250
1	Drafting table - 4 legs, upright, tilt top plus drawer	80
1	Desk or metal table, plastic top	40
1	Drafting stool	15
2	Office chairs	40
1	4-drawer locking, metal filing cabinet	-
2	Dazor lamps flexible, with desk attachment	30
2	Steel tapes 300 foot, gun-metal blue graduated feet, tenths and hundredths	120
2	Steel tapes 100 meter, gun-metal blue	120
2	Steel tapes 100 foot, gun-metal blue graduated feet, tenths and hundredths	40
2	Steel tapes 30 meter blue	40
2	Geologist's picks	5
2	Hand lenses (12 x and 14 x)	30
1	Brunton compass	40
1	Price current meter, calibrated with wading rods and phones	150

2	Stop watches	40
	Camping equipment including 2 light weight Safari-type tents with mosquito net lining, 2 light-weight "woods" sleeping bags; 2 light weight canvas flies with grommetts	300
2	Trapper Nelson type pack boards with canvas bags	35
2	Cots, army type, folding	30
2	Air mattresses	30
2	Stoves, coleman 3-burner	30
4	Lamps, colemen, single mantle	24
2	Cooking kits, nest, 4-man	8
		$21,292

* For beginning phases of the overall project and for use in this proposed project 1,000 individual photographs, scale 1/50,000 should be provided to cover the 1-degree quadrangles in Ethiopia.

(1) 3°00' N to 4°00' N Latitude; 38°00' E to 39°00' E Longitude
(2) 4°00' N to 5°00' N " ;; " " "
(3) 5°00' N to 6°00' N " ; " " "

Each 1-degree quadrangle should be illustrated by print-laydowns Scale 1/125,000.

APPENDIX

The long-range Regional Livestock Development program for Southern Etniopia including development of the water-supply has been agreed to by the Ethiopian government. A part of this program calls for contract documents covering the drilling of exploratory and test boreholes in the development area, and initiation of this work as soon as possible. Plate 1 illustrates six sites chosen for exploratory boreholes in areas where they should have a reasonable chance of encountering sufficient water for livestock. Three of these sites are south of Mega, in the central part of a broad valley leading southward from the hills surrounding Mega; two are northwest of Mega along the axis of a similar valley and one is in a low-lying area about one mile northeast of the air strip at Mega. The sites can be reached by road with an interval of cross-country driving.

The three borehole sites south of Mega are believed to be underlain by tuffaceous sediments covered with a thin veneer of alluvial sand and clay. These tuffaceous sediments probably rest uncomfirmably upon the igneous and metamorphic rocks that crop out in the hills of Mega. A borehole at the site nearest the hills of Mega may encounter only a thin sequence of tuffaceous sediment, or it may penetrate from alluvium directly into metamorphic rocks. It is the least likely to encounter water-bearing rocks of the three sites south of Mega. Boreholes at the two southern most sites should encounter water in fuffaceous sediment at between 80 and 120 feet below land surface datum.

The two borehole sites northwest of Mega are believed to be underlain by poorly stratified alluvial deposits of sandy silt. These deposits may in turn rest upon volcanic or upon metamorphic rocks. Very little can be safely predicted concerning the depth to water, the nature of the water bearing sediments, or the yield of boreholes at these two sites, but the prevalence of green vegetation along the axis of the valley suggests that ground water may be present at shallow depth below the land surface in alluvium.

The borehole site about one mile northeast of the Mega air strip is believed to be underlain by volcanic rocks that have originated from nearby explosion craters. The thickness or the physical properties of these deposites is not known. They are believed to rest unconformably upon metamorphic rocks. Ground water may be encountered in the lower part of the volcanic sequence directly above the metamorphic sequence of rocks.

At none of the proposed borhole sites should drilling attempt to go beyond depths at which metamprphic or igneous rocks of the basement complex are first encountered.

Provision in a contract covering drilling activities at these sites should include the following:

1. Representative samples of all strata penetrated at each borehole shall be collected at 10-foot vertical intervals add at any interval in depth at which water-bearing rocks are first encountered or where drilling rates or other conditions indicate a change in the physical properties of the strata. These samples should be logged by a qualified geologist and the cuttings, in apropriate wooden containers, and the logs, turned over to representatives of USAID.
2. Electric logs including a resistivity and self-potential log shall be provided by the contractor and become a part of the documentation of each borehole.
3. Boreholes shall be of sufficient diameter to accomodate 6-inch I.D. A.P.I. casing. Casing shall be installed throughout the depth of the borehole and slotted sufficiently to allow optimum conditions for entry of water and elimination of detritus from walls of the borehole.
4. Each borehole shall be developed over a sufficient period of time to insure the removal of drilling mud from water-bearing strata and other fine-grained sediment that might, during its subsequent use, impare its efficiency or cause damage to installations.
5. Casing shall be recovered at abandoned boreholes and the cost of the casing less the cost of its installation and recovery shall be reimbursable to the U.S. Government at prices and rates stipulated by the contract.
6. Each borehole initiated by the contractor must be originated by a work order from a U.S. representative in-charge documenting the design and objectives of the borehole and its estimated cost.

7. Each borehole completed by the contractor must be terminated by a certificate of Work Satisfactorily Completed documenting the various rates, costs and items performed by the contractor, this document being the statement upon which payment to the contractor shall be based.
Other pertinent data are included in an edited sample contract entitled Chad Basin, Water Supply investications (Well Drilling). Attached 1 copy only.

Items for which rates and prices shall be provided by the contractor include the following:

1. Moving equipment to site area for work there and removal from that site area upon completion

EACH SITE AREA THE SUM OF

2. Erection of equipment at a drilling site, dismantling upon completion

EACH SITE THE SUM OF

3.(a) Drilling from surface to full depth drilled, at such diameter as is necessary for completion of a well at 6" i.d.

AT PER FOOT

(b) Drilling at such diameter as is necessary for the lining of a well at 6" i.d. AT PER FOOT

4. Supplying and installing 6" API Line Pipe as well lining

AT PER FOOT

5.(a) Cleaning out and developing of 6" i.d. well

THE SUM OF

(b) Provide and install airlift equipment in 6" i.d. well and compressor also, remove upon completion of testing

THE SUM OF

(c) Operate compressor for airlift pumping

AT PER HOUR

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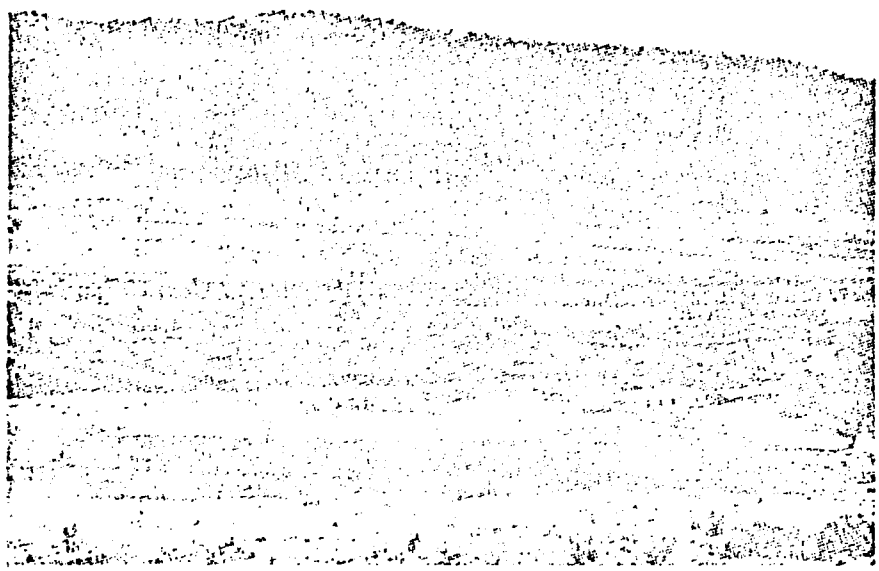

Fig. / Iavello, Sidamo Province, Southern Ethiopia. View to north.

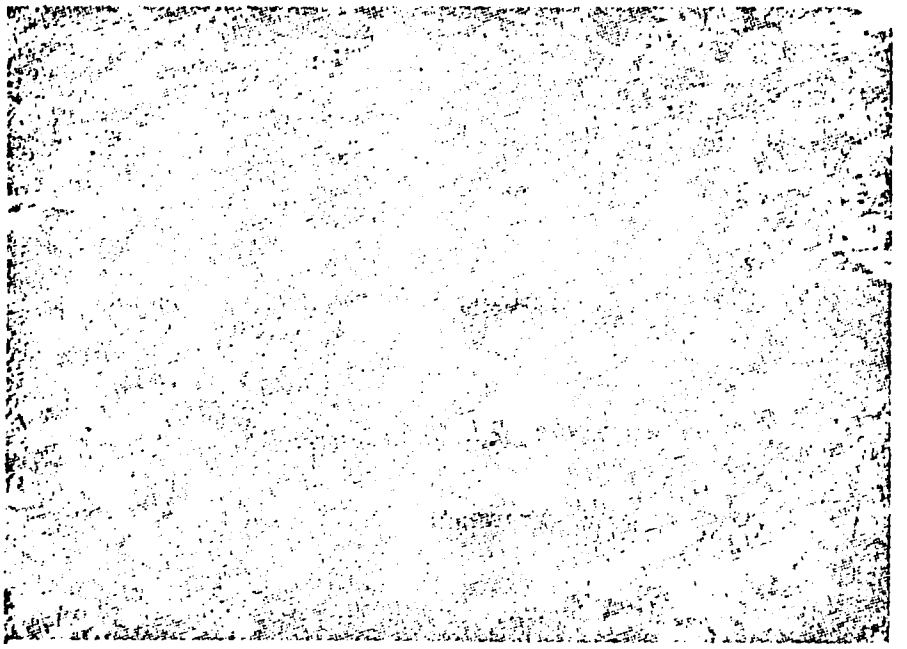

Fig. 3 Air view of thorn bush and acacia and undercover of grasses. Thirty miles west of Mega, Sidamo Province, Southern Ethiopia. Air photo from 500 feet altitude.

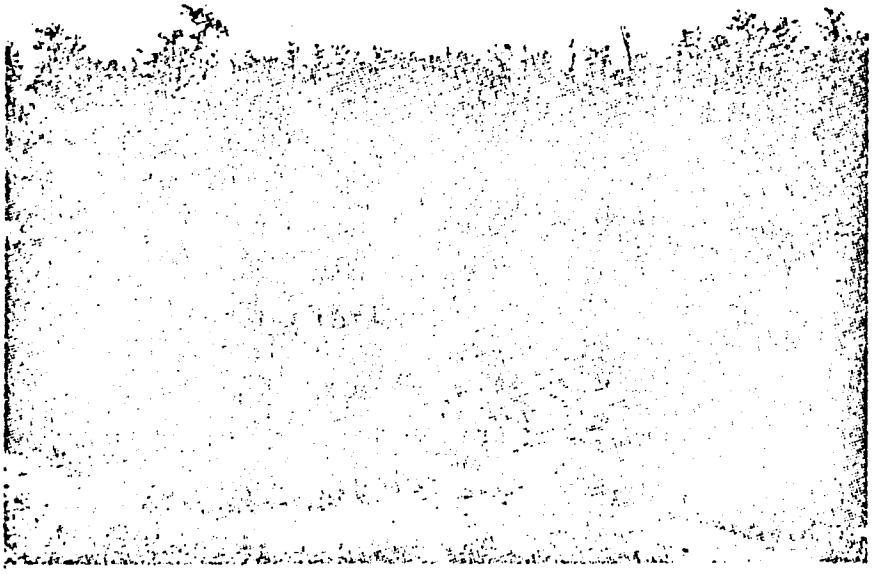

Fig. 2 Mixed cedar, thorn bush, and Euphorbia forest in hills 5 miles west of Javello, Sidamo Province, Southern Ethiopia.

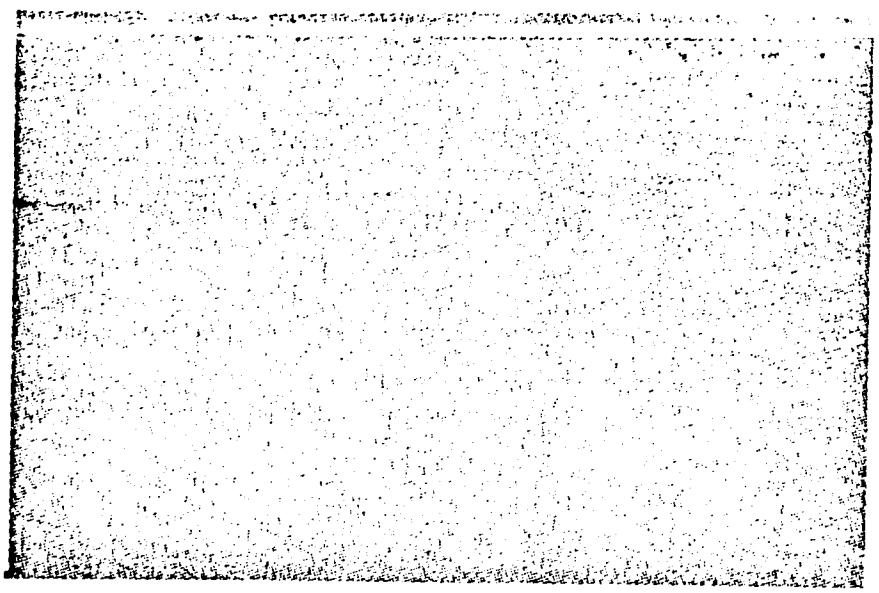

Fig. 4 Grassy plains in wildlife area 30 miles southwest of Iavello, Sidamo Province, Southern Ethiopia.

Fig. 5 Salt lake in floor of El Sod. An explosion crater. Capping on crater rim is basalt, the inner walls are metamorphic rocks of the basement complex. View to north. Sidamo Province, Southern Ethiopia.

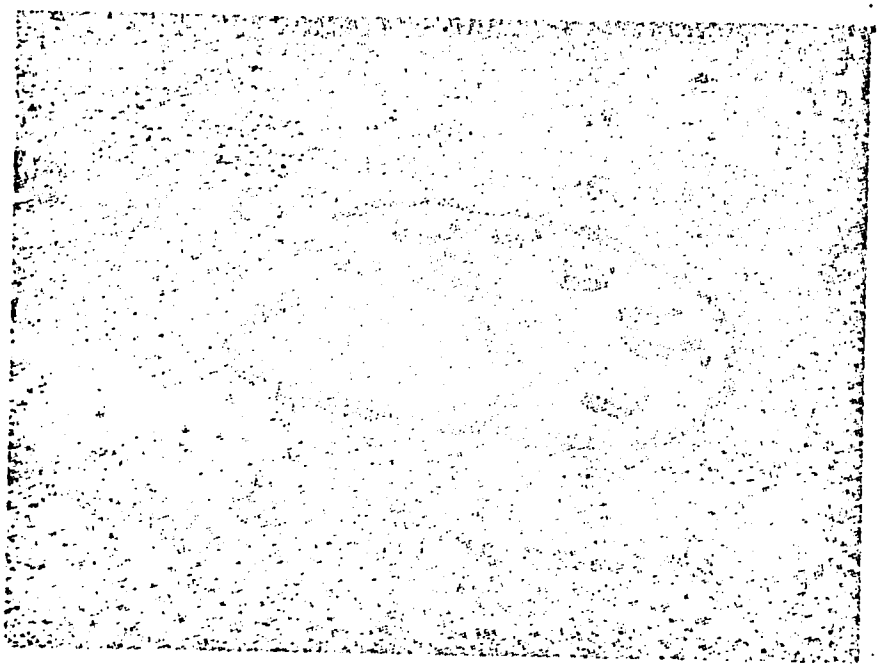

Fig. 6 Borana family village near Iavello, Sidamo Province, Southern Ethiopia.

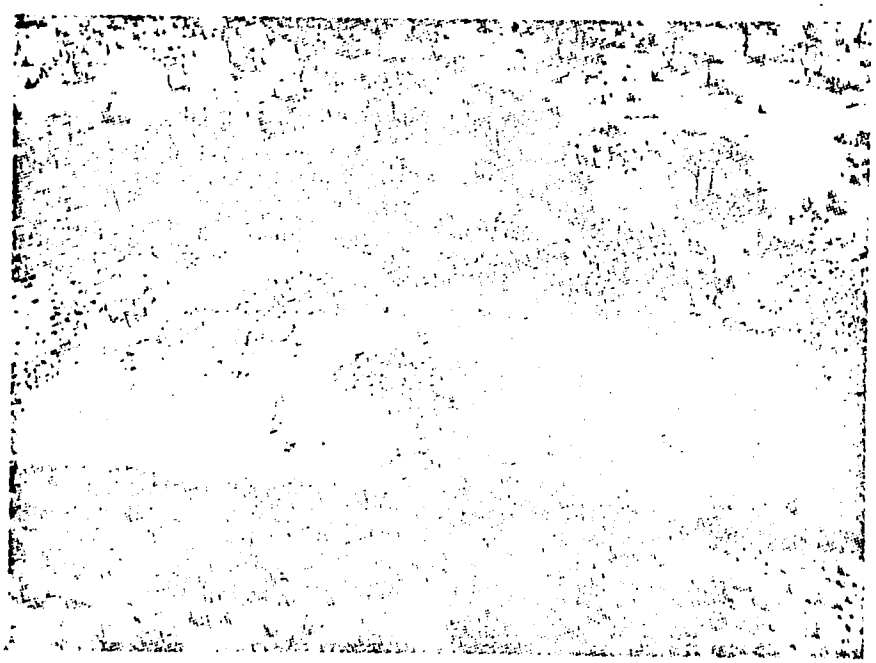

Fig. 7 Herdsmen watering livestock along the Daña Parma, Sidamo Province, Southern Ethiopia.

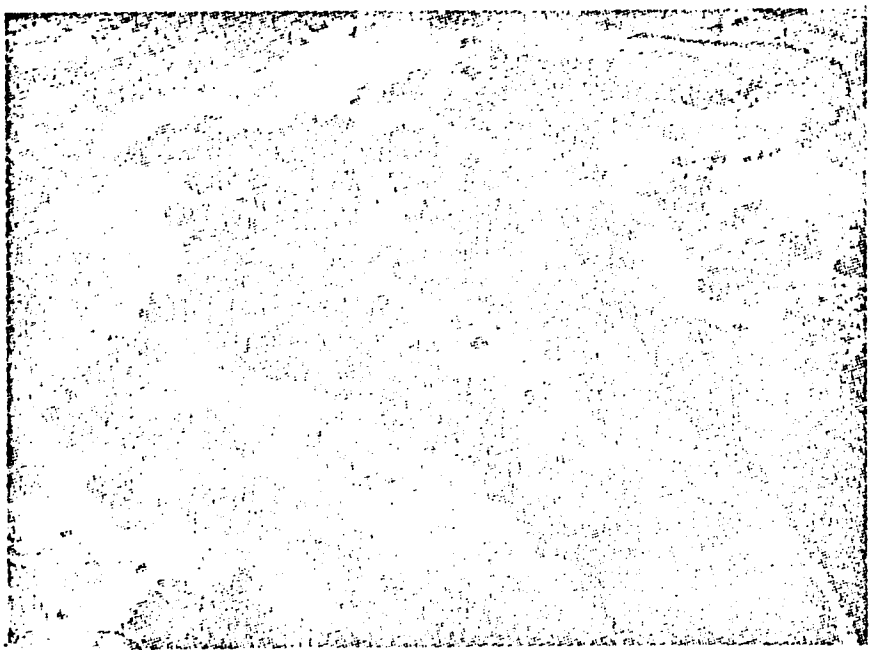

Fig. 8 Air view of Soghidda wells, 27 miles southeast of Mega, Sidamo Province, Southern Ethiopia. Air photo from 1,000 feet altitude.

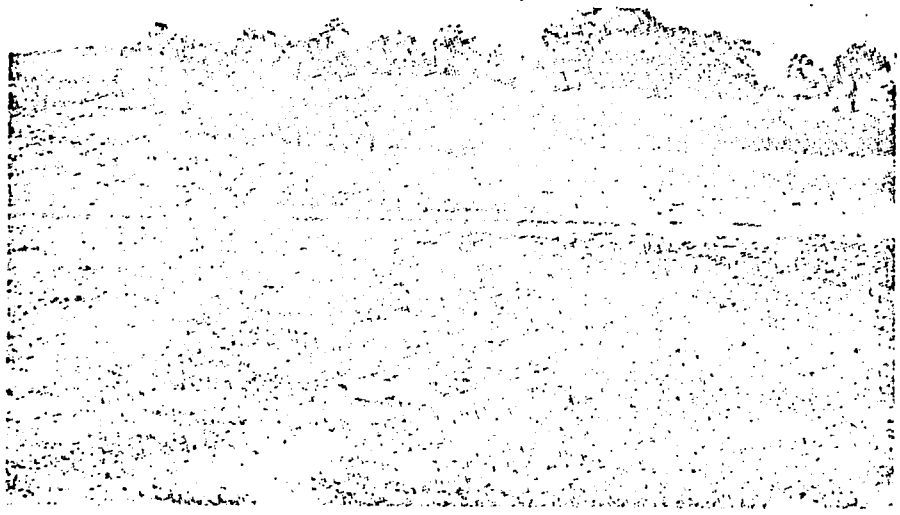

Fig. 9 Thorn bush corral and entrance way to El (well) Melbana, 22 miles southeast of Mega, Sidamo Province, Southern Ethiopia.

Fig. 10 Incline leading down to cattle watering stage in foreground. Well near Mega, Sidamo Province, Southern Ethiopia.

Fig. 11 Cattle watering stage. Twenty feet below general land surface. El Melbana, Sidamo Province, Southern Ethiopia.

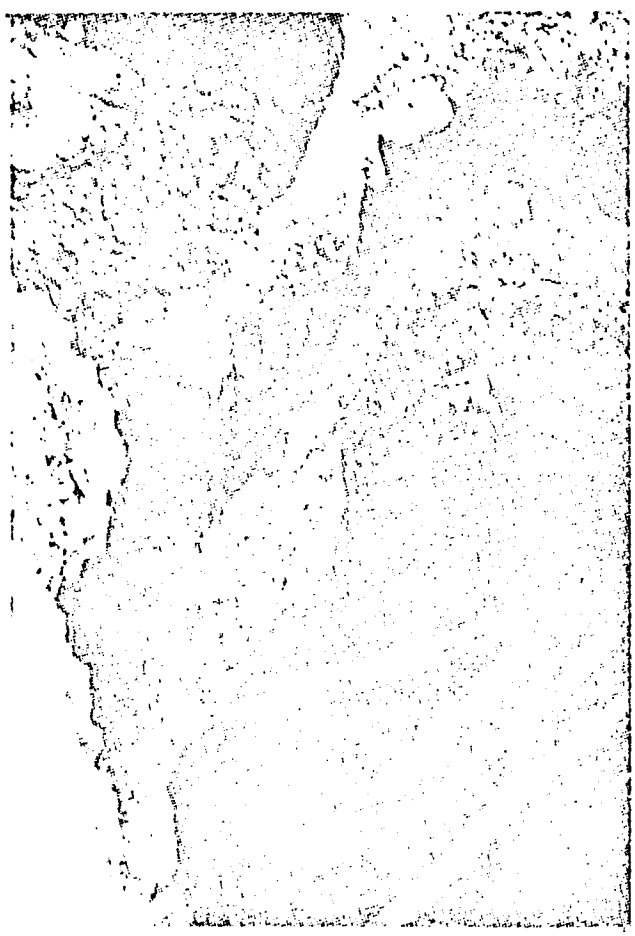

Fig. 12 Uppermost lifting stage 60 feet above water level, El Melbana, Sidamo Province, Southern Ethiopia.

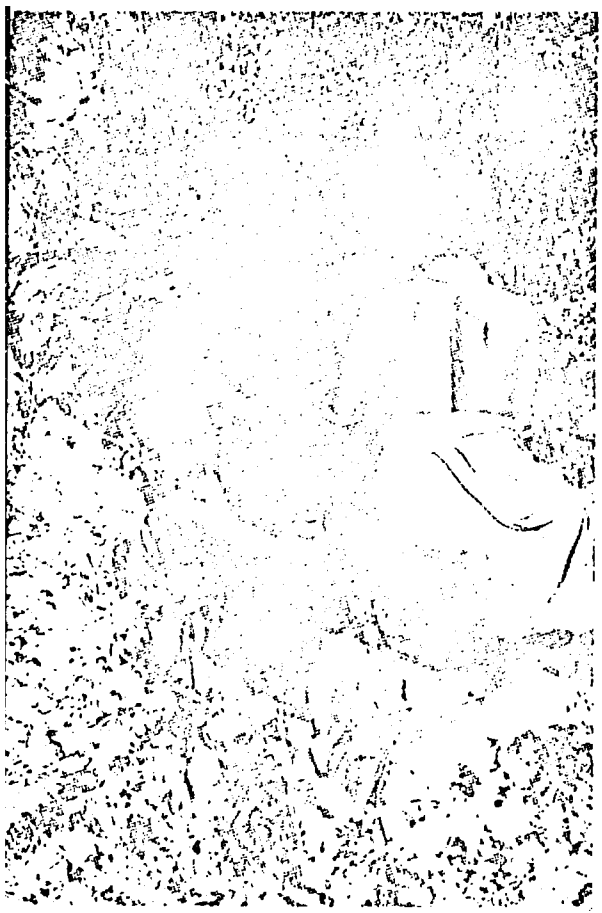

Fig. 13 Watering cattle from well near spring 1 mile south of Mega, Sidamo Province, Southern Ethiopia.

Fig. 14 Watering cattle from well near spring 1 mile south of Mega, Sidamo Province, Southern Ethiopia.

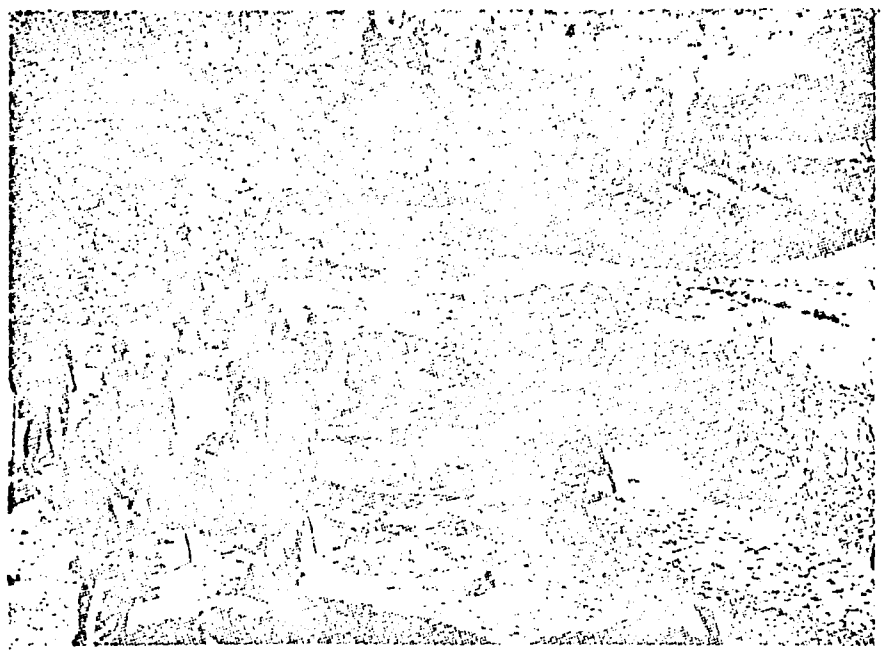

Fig. 15 Herdsmen watering cattle and removing silt from small stock pond 23 miles northeast of Mega, Sidamo Province, Southern Ethiopia.

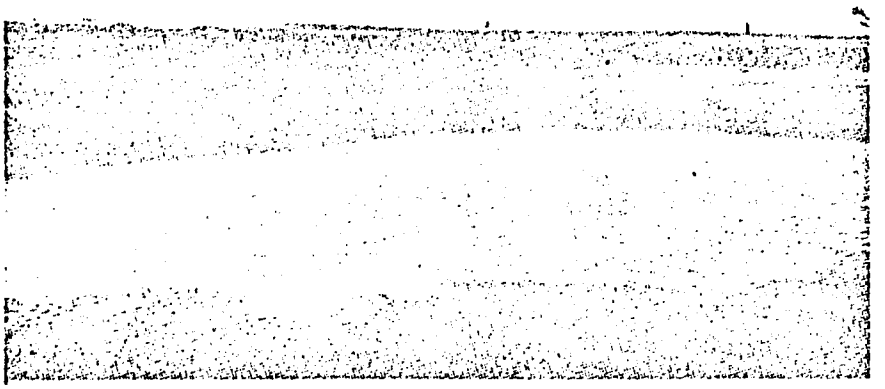

Fig. 16 Three-year old stock pond, base of hills 4½ miles northeast of Mega, Sidamo Province, Southern Ethiopia. View to east.

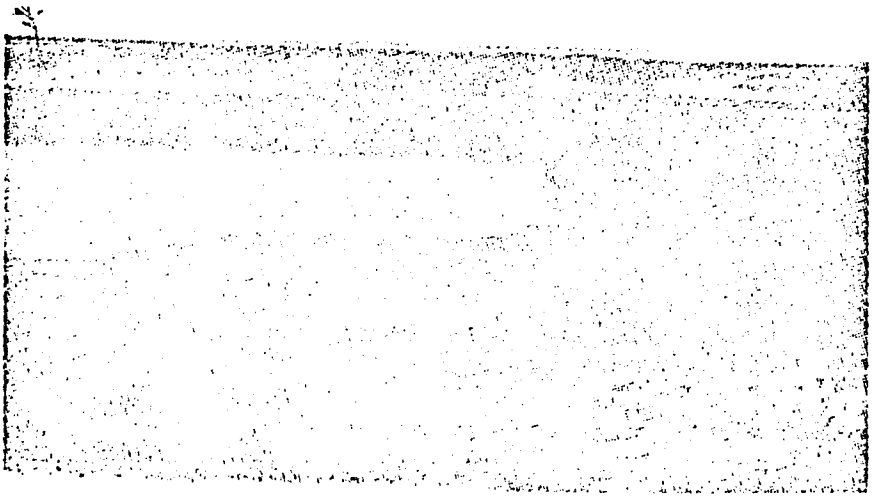

Fig. 17 Three-year old stock pond, base of hills 4½ miles northeast of Mega, Sidamo Province, Southern Ethiopia. View to southeast.

Fig. 18 Digula stock pond, 22 miles southeast of Iavello, Sidamo Province, Southern Ethiopia.

Fig. 19 Eroded surface of the basement complex rocks, Digula stock pond, 22 miles southeast of Iavello, Sidamo Province, Southern Ethiopia.